ARS-74-21

CONFERENCE ON FROZEN FOOD QUALITY

—

Held at Albany, California
November 4-5, 1960

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

CONTENTS

THE PURPOSE OF THE CONFERENCE ON FROZEN FOOD QUALITY held November 4 and 5, 1960 in the Western Regional Research Laboratory was to enable groups concerned with industrial problems in the handling of frozen foods to hear and discuss research results in a comprehensive manner.

Those attending were chiefly representatives of the Association of Food and Drug Officials of the United States and of the Frozen Foods All-Industry Coordinating Committee. The research results reported were largely those obtained in the project on time-temperature tolerance of frozen foods, conducted by the Western Utilization Research and Development Division of the Agricultural Research Service, U. S. Department of Agriculture.

The conference was arranged by this Division in cooperation with The Refrigeration Research Foundation.

The discussions centered on problems in the packing, transport, warehousing, distribution, and retailing of frozen foods -- particularly those related to recent proposals for performance standards in frozen-food handling from packer to consumer.

This report contains the results of research presented by staff members of the Western Utilization Research and Development Division and also a review of technical literature on the microbiology of frozen foods. The latter report was prepared especially for this conference. Others who presented reports or took part in the panel discussions were invited to submit material for this report, and all contributions submitted are included. The complete program is shown on the following page.

This report was prepared in the Western Regional Research Laboratory, Albany, California--headquarters of the Western Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture.

CONFERENCE ON FROZEN FOOD QUALITY

Western Regional Research Laboratory, Albany, California

November 4, 1960--AM

Chairman	W. F. Talburt, WRRL[1]
Introduction	M. J. Copley, WRRL
The Critical Problem of Quality Evaluation	Hans Lineweaver, WRRL
Calculation of Quality Change from Time-Temperature Records	D. G. Guadagni, WRRL
Relative Stabilities of Frozen Foods	A. D. Shepherd, WRRL

PM

Chairman	Evan Wright, AFDOUS[1]

Tour of Laboratory

Panel Discussion: Industry Problems in Handling Frozen Foods

Moderator: Cliff D. Carpenter, Consultant

Members (FFAICC)[1]: Fred Otterbein, packers; Milton D. Ratner, truckers; Paul D. Burrill, warehousemen; J. Tom Kirk, distributors; Lee D. Smith, retailers

November 5--AM

Chairman	C. S. Brinsfield, AFDOUS
New Developments in Refrigerated Trucks	P. R. Achenbach, National Bureau of Standards
Effects of Processing Variables on Quality of Frozen Foods	D. G. Guadagni, WRRL
Objective Tests for Frozen Food Quality	R. L. Olson, WRRL
Review of Microbiology of Frozen Foods	R. P. Elliott and H. D. Michener, WRRL

PM

Chairman	Walter A. Maclinn, The Refrigeration Research Foundation
Marine Transport of Frozen Foods	L. L. Westling, Marine Refrigeration Specialist

Panel Discussion: Microbiological Standards for Frozen Foods

Moderator: Emil Mrak, Chancellor, University of California at Davis

Members: Glenn G. Slocum, Federal Food and Drug Administration; M. F. Gunderson, Campbell Soup Company; Harry E. Goresline, Quartermaster Food and Container Institute; P. J. Brandly, Meat Inspection, U. S. Department of Agriculture

Recapitulation and Evaluation	M. P. Duffy and Harold Clark, AFDOUS, and H. C. Diehl, FFAICC

---

[1] WRRL: Western Regional Research Laboratory, headquarters of the Western Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

AFDOUS: Association of Food and Drug Officials of the United States.

FFAICC: Frozen Food All-Industry Coordinating Committee.

EXPERIMENTAL PLANS AND METHODS

William F. Talburt
Western Regional Research Laboratory
USDA, Albany, Calif.

In 1948 a research project was undertaken at this Laboratory which was designed to provide detailed and quantitative information about frozen foods. This project was considered by leaders of most segments of the industry to be urgently needed. Today, twelve years later, we are gathered here to discuss results of this unprecedented project, now almost completed.

Since I was not involved in the early planning of this work, I feel that I can speak freely and objectively about the planners and the prime movers who were involved in this project. First, I would like to say that these people representing the various segments of the frozen food industry showed remarkable foresight. The results to be presented at this meeting are the direct outgrowth of their vision and long-range planning. And secondly, these people overcame a number of obstacles and even found ways to obtain rather substantial amounts of money required for facilities and personnel to get a project of this magnitude under way. While I plan to refrain from mentioning names in this connection, I do feel that H. C. Diehl, Chairman of the Frozen Food All-Industry Coordinating Committee, deserves special recognition. In my opinion, it is doubtful that this project would have been undertaken at this early date of 1948, or perhaps not undertaken at all, had he not supported the work so enthusiastically and so effectively.

I would also like to recognize the contributions of another individual, who is on our Laboratory staff, and who made major contributions to the project. Although W. B. Van Arsdel is not on the program of this meeting, a number of his ideas will be presented by the various speakers. In fact, I have leaned very heavily on the first of the series of TTT (Time-Temperature Tolerance) papers authored by Mr. Van Arsdel for material for my presentation today. His introduction to this series, though written over four years ago, has withstood the test of time. I do not say this facetiously, since four years <u>is</u> a long time in a fast-moving industry such as frozen foods.

When this project was being planned, World War II with its strict manpower controls and drastic restrictions on equipment and supplies, had ended only a few years earlier. The markets of the abnormal war years had changed drastically and the frozen food industry had been shaken badly by low prices and large inventories of low-quality merchandise. The industry in 1948 was again moving forward and was anticipating the rapid expansion and increased consumer acceptance that actually did occur during the next decade.

At that time, the frozen food industry was faced with a number of questions that needed to be answered if maximum growth was to be achieved. Were the practices used in handling frozen foods, which had developed during the depression and war years, really doing a satisfactory job? Were the warehousing, transporting, and retailing equipment and facilities adequate? How much equipment and how many facilities should be modified or replaced in

order to handle frozen foods properly? What, in fact, were the specifications for a satisfactory distribution system? Such a system must not only be capable of maintaining frozen products in excellent condition up to the point of delivery to the consumer, but also it must be economically feasible. Even before 1948, many people were talking of 0°F. or even lower as the temperature to be maintained at all times. Harold Humphrey commented that the ideal system would be a refrigerated tunnel extending from the packing plant to the home freezer. However, he recognized that for some time something short of ideal would have to be accepted.

Since it was generally recognized that the temperature of most, if not all, frozen foods did deviate upward from 0°F. by various and even unknown amounts, for fairly substantial periods of time, it was becoming increasingly evident that a much better understanding of the effects of time and temperature on the quality of frozen foods was needed.

This was the picture in 1948 when various industry groups approached our Laboratory with requests that steps be initiated to provide urgently needed information about the effects of time and temperature on quality of frozen foods. Early in these discussions it became obvious that this must be a very extensive study if it was to provide reliable information for the industry, and that it would require several years to complete. Incomplete information or erroneous conclusions might result in great financial losses to the industry.

There were a number of questions to be answered if the industry was to have the information that it needed:

1. What quality changes occur to frozen foods during their flow through conventional distribution channels?
2. What is the effect of fluctuating temperatures on the quality of frozen foods?
3. Are the effects of adverse temperature exposures on frozen foods cumulative and additive?
4. Does the order of the sequence of a series of temperature experiences affect the extent of quality deterioration?
5. What is the effect of variety on rate of quality loss?
6. Does the growing season or producing area affect the rate of quality losses encountered at various storage temperatures?
7. What effects do the actual processing procedures have on initial quality and on stability of product during subsequent storage?

Today and tomorrow you will hear these questions discussed. For most of these, definitive information is available.

With funds supplied by the Department in 1949, construction was started on special rooms to be used in the experiments. These rooms were equipped with adequate shelf space for holding hundreds of individual retail packages of frozen foods. Circulation of refrigerated air at carefully controlled velocities around each package was provided by way of the perforated walls of the plenum chamber back of the shelves. This was essential, since the temperatures of primary interest were those experienced by the frozen product itself rather than air temperature. In all experiments where samples

were exposed to irregular or fluctuating temperature patterns, the rate of change of air temperature was such that temperature of the frozen foods closely paralleled the temperature of the air circulating around the samples. Thus, by controlling temperature of the air circulating within the room, one could be sure that the temperature of test samples followed air temperature. Equipment for automatic program-control was provided, so that any desired temperature pattern could be scheduled and this schedule maintained by heating or refrigerating the air circulating within the test chamber. The size of the project, which required in excess of 100,000 individual retail packages of frozen fruits, vegetables and poultry, required the construction of a battery of nine of these test chambers. Two smaller test chambers of less elaborate design were installed in the Pasadena Laboratory.

While the rooms were being constructed, preliminary plans were being made and information was being gathered about the temperatures experienced by frozen foods during distribution. Our own staff obtained the temperatures of many samples of frozen foods from retail stores in this area; other research groups in the USDA were already surveying the temperatures and times experienced by frozen foods during distribution; the Pacific Fruit Express and American Association of Railroads were measuring temperatures of frozen foods in cross-country shipments; the Birds Eye Division of General Foods Corporation and others were actively engaged in securing information in this field.

By 1950 preliminary planning had been completed, sufficient facilities and personnel were available, and active work was initiated. Frozen stawberries were the first commodity studied. As many of you have been told on various occasions, we had three primary objectives in this study:

1. To determine how frozen food products behave under conditions of time and temperature such as they may actually experience in the commercial distribution system, and in this way to provide information comprehensive enough to enable industry to (a) settle upon and specify allowable or tolerable deviations from "ideal" distribution conditions and (b) concentrate efforts on improvement of the more critical operations or areas in the system,
2. Upon the basis of these results, to discover or devise improvements in raw material selection and handling, processing, and packaging, such that the finished product would better withstand adverse subsequent experiences, and
3. To seek tests of product quality that could be applied to a frozen food at any point in the distribution system, to indicate how much it has changed and, if possible, to estimate where it stands in the scale of commercial acceptability.

The major objective -- that of determining how frozen foods behave at various temperatures -- was particularly challenging because of the practical impossibility of duplicating all of the variations in temperature and time that may be experienced by frozen foods in the actual distribution system.

Specific planning of experiments in which samples were to be subjected to time-temperature schedules simulating those that may occur in actual commercial distribution involved selection of a reasonably small number of

reproducible time-temperature patterns that, as a group, would substitute acceptably for the infinite variety of actual patterns. It was not sufficient to carry samples through a temperature history simulating "average" conditions, since something like half of the frozen foods in our markets experience worse treatment. The planning included enough variations to cover the range between "probably satisfactory conditions" and "almost certainly unsatisfactory conditions" with a large number of single variations in pattern to enable the investigator to separate effects. Times and temperatures selected for the project included steady temperature storage ranging from -10°F. to +40°F.; temperatures fluctuating in a 24-hour sine wave pattern and ranging from -10°F. to +30°F.; and conditions actually simulating the temperature history of frozen foods during transport, warehousing, distribution, and retailing.

The second objective -- that of improving processing procedures which would lead to products with greater stability -- has led to a better understanding of some of the processing problems and in certain instances have pointed out deficiencies and poor practices in some of the plants processing frozen foods.

The third objective -- to develop tests of quality which might be applied to products at any point in the distribution system -- has been rewarding. Several have been developed but the full significance of these still remains to be determined by large-scale testing. Other objective tests -- appropriate for many kinds of frozen foods -- need to be devised.

In view of the importance of the overall problem, planning for the work laid stress on assuring conclusiveness of results. We sought to guard against findings based on atypical materials by repeating procurements in two or three packing seasons and by obtaining samples from each of the major producing areas for most of the various commodities.

For frozen fruits and vegetables, these conditions virtually dictated the use of commercially packed materials. In addition, however, small experimental packs were included in the tests in some cases to furnish additional information about the effects of processing variables. Poultry products and precooked foods were in part prepared in the laboratory, in part purchased from commercial producers. Use of commercially packed products, of course, offered the additional advantage that when a sufficiently broad selection was made, the results of the work would undeniably be directly applicable to industrial operations. Purchased lots of the various commodities were usually packed in the presence of a member of our staff; full information on the raw material and processing conditions was obtained. Some lots were of commercial Grade A product, and others Grade B. The major commercial freezing methods were represented by lots procured from the various plants. Shipments to the laboratory were made at below zero temperatures.

Commodities included in the study were strawberries, peaches, red sour cherries, raspberries, concentrated orange juice produced in California, fruit pies, peas, green beans, spinach, cauliflower, whole ready-to-cook poultry, cut-up chicken fryers, cut-up stewing hens, several pre-cooked poultry products, and sauces and gravies used in pre-cooked items. Just recently studies on bulk-pack fruit in 30-pound containers have been completed.

During the next few minutes, I would like to take up one specific commodity -- green beans -- and describe briefly just what was done over the six-year period that this commodity was under study. Because of time limitation, it will be necessary for me to go through this quite hurriedly and talk in rather general terms. However, I hope that this procedure will give you a better understanding of the techniques used. While the approach may have been somewhat different with other commodities, in general the same basic procedures were used throughout the entire project.

Ten large lots of frozen beans were obtained over a four-year period from five of the principal producing areas.

Table 1. Sources of samples of frozen green beans

Commercial retail packs selected at the processing plant

Crop Year	Variety	Growing Area
1952	Blue Lake	Oregon
1952	Top Crop	New Jersey
1953	Blue Lake	Oregon
1953	Top Crop	New Jersey
1954	Blue Lake	Southern California
1954	Tendergreen	Tennessee
1955	Blue Lake	Southern California
1955	Tenderlong	Tennessee
1955	Blue Lake	Santa Clara Valley, Calif.
1955	Blue Lake, French Cut	Santa Clara Valley, Calif.

Each lot consisted of from 700 to 1200 individual packages or a total of approximately 10,000 samples. Nine smaller lots of 100 to 200 samples each were also obtained. After transport to the laboratory by air or railway express packed in dry ice, they were held in storage for a short time at -20° or -30°F. until they could be put under test.

Samples were placed in the test chambers previously described and exposed (a) to a variety of temperature patterns simulating several degrees of adversity in distribution conditions; (b) several temperature patterns designed to test the additivity of temperature effects; and (c) temperatures fluctuating over several different ranges and to steady temperatures maintained at -10°, 0°, 10°, 20°, and 30°. Those at lower temperatures were held for periods of time up to three years.

Samples were removed from the test chambers according to planned schedule and were examined subjectively by trained panels for changes in texture, color, and flavor and objectively by measurement of chemical and physical changes occurring during the storage periods. Objective testing included routine assay for ascorbic acid -- vitamin C -- content, determination of the amount of chlorophyll that had been converted to pheophytin, and reflected color as measured by special color analyzing equipment. Total bacteriological counts were also made.

Organoleptic examination was accomplished by submitting to a trained taste panel one sample that had been stored for a given time at say 10°F. temperature and a control sample from the same lot of frozen beans which had been stored at -30°F. Previous experiments had shown that changes at -30°F. are imperceptible for several years. Thus we were comparing one sample essentially unchanged since it left the freezing tunnel with a sample stored a given number of days at a selected temperature.

The panel was asked if there was a color or flavor difference between the two samples. This was repeated, using other samples of course, at increasing storage times until the panel could detect a difference in color and flavor between the two samples. This amount of change, which may be called the first detectable difference, is reproducible and has been an indispensable tool in this project. Statistical calculations of results are straightforward and fairly simple. Other speakers during the meeting will discuss this method of organoleptic appraisal and its significance. This same procedure was repeated for other storage temperatures. Obviously, decreasing times were required to produce the first detectable change as the temperatures increased. By finding the time required to produce this first change in flavor or color at several temperatures, it is possible to calculate the rates of change at the various temperatures.

We have taken some preliminary steps to relate this first detectable difference to consumer complaint point, but our information in this field is very sketchy. This will be mentioned by other speakers.

Since we were measuring the rates of change of ascorbic acid, chlorophyll and certain other factors, as well as changes in flavor and color, we also obtained information which would enable us to make conclusions such as this: "A change in flavor of frozen green beans perceptible to 75 per cent of the taste panel is accompanied by a 10 percent loss of chlorophyll, a loss of 1.8 mg/100 grams of vitamin C, and a certain amount of change in reading on the color analyzer." This type of information was used in developing objective quality tests which will be discussed later.

If I haven't lost you by this time, you are probably wondering if all these lots of beans were alike. The answer is no; they were not all alike. We have plotted, for several different lots of beans, the time required at several storage temperatures to cause a 7 per cent loss of chlorophyll against the respective storage temperatures.

Had the samples been alike, all the lines on the graph at the left

of Figure 1 would coincide. Thus, we know that they are not all alike and we have a measure of the deviation between the several lots. We know that this deviation is due to a number of different factors: processing differences, variety, growing area, seasonal variation, cultural practices, and perhaps others. It is not possible to sort out the magnitude of these effects one from the other but we do know that processing plays a greater role in this than any of the other variables.

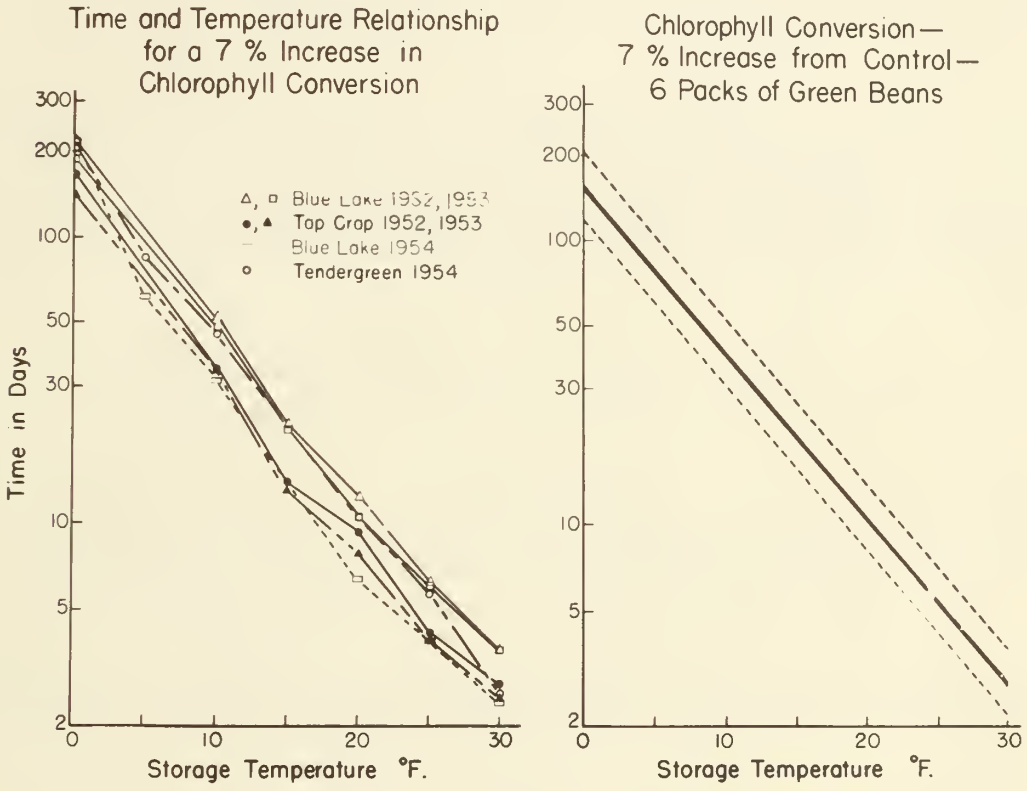


Fig. 1. Variability of samples of green beans.

The figure on the right of Figure 1 shows a solid line -- an average or calculated line for the several lines in the left-hand chart. And, if our samples are representative of all frozen beans, then 90 percent of the lines you would obtain from other samples would fall within the two dotted lines. This gives us a measure of the statistical accuracy of our data.

THE CRITICAL PROBLEM OF QUALITY EVALUATION

Hans Lineweaver
Western Regional Research Laboratory
USDA, Albany, Calif.

The time-temperature tolerance studies have been concerned with relative rates of change in quality and therefore have required extensive quantitative measures of changes in experimental samples. Because the evaluation of quality change is so basic to the TTT studies and because quality evaluation results are subject frequently to various interpretations, a discussion of the methods used seemed worth while at this point in the conference.

The discussion will concern the characteristics of organoleptic methods, which, of course, are the primary methods of measuring quality. The several variations of methods used have the feature in common that trained taste panels were employed to determine how long it takes under the conditions of the experiment for the first definitely detectable change to occur. Measurement of the first change is appropriate, since it is obviously desirable to preserve the initial quality of foods so far as possible.

This first measurable change may be considered to be one unit of change -- the smallest unit that can be determined with the selected procedure. Therefore, this unit of change, expressed in units of time, might be referred to as a first detectable unit of change, the time required for a significant change, a unit of initial-quality life, a unit of high-quality life, or possibly other similar terms. The term used is of secondary importance. What is determined is the relative rate at which the first stage of deterioration occurs in the various samples. Generally, but not necessarily always, the initial rates of change are equal to or greater than the rates at later stages of deterioration.

This type of unit has proved very useful in providing information about temperature coefficients and about the influence of packaging, processing, or other conditions on stability. Information obtained under a variety of conditions has been expressed in terms of equivalent exposure to a reference condition. For example, changes occurring during storage at a high temperature or a combination of temperatures have been expressed in terms of the time it would have taken for the same change to occur at a reference temperature such as 0°F.

Definition of the unit of initial change. The unit of change used in most of the TTT studies is the amount of change that the product has undergone, under any given condition, at the time it becomes definitely distinguishable from the control by an agreed upon sensory (taste or color) panel procedure. It is assumed and supported by experience (a) that panels have about the same acuity from time to time; and (b) that two or more samples that are just detectably different from controls will have undergone approximately equivalent treatments. Thus, if the first detectable change in a product occurs after 2 months at 20°, 4 months at 10°, and 12 months at 0°F., it is considered that those exposures are approximately equivalent. The relative rates of change are proportional to the reciprocals of the times involved and are therefore 0.5, 0.25, and 0.08 unit per month, respectively.

Determination of quality change. Sensory tests are used to determine quality changes for several reasons. A change in flavor, color, or appearance is of practical importance only if it can be detected by the human sense organs. Nutritive value generally changes less rapidly than organoleptic values and is therefore a less sensitive indicator of change, though not unimportant. Chemical tests are available only in certain cases and in any case must be standardized against sensory tests.

Three sensory tests were used at this laboratory: triangle, paired comparisons, and ranking tests. They have the common attribute of determining whether a sample differs significantly from a control. As such the tests are not quantitative; that is, they do not reveal how much different the sample is from the control. But quantitative information in relative terms is obtained when the panels are used to determine how long it takes for a definitely detectable difference to develop, since this amount of change, though unknown, is the same essentially from sample to sample for a given product. We can determine the time required by testing samples removed from storage at various appropriate times. The three tests differ in the number of samples that are compared with the control (one with a triangle or paired comparison test and one or more with the ranking test, depending on the limitations of the taste panel). No matter which of the test methods was used, comparisons were replicated sufficiently to level out sample and other random type variations and to make possible statistical analysis of the results. All panels had at least 6 judges to reduce the error caused by day to day variations in reaction of individuals.

Relation between one unit of quality change and consumer complaint. The relation between the time a product can be stored without changing enough to cause consumer complaint and the time it must be stored to produce a change that is definitely detectable by a trained panel is not known. A comparison of the conditions used for the trained panel tests and the conditions under which food is ordinarily consumed makes it appear that the time-to-the-consumer-complaint point would greatly exceed the time-to-the-detectable-difference point.

Pertinent factors are the following: The panels of judges used for the laboratory tests were selected for their ability to distinguish very small differences in the particular product examined under relatively ideal conditions in side-by-side comparison with a control. Each judge is in a booth by himself during the test, so that he is not distracted by others and can concentrate fully on the task at hand. The products are seasoned a minimum amount. In contrast, under ordinary conditions of eating, the food is consumed as part of a meal, seasoned, often combined with other foods, and the attention of the consumer is focused on many things -- foods and people -- at the same time.

It may be worthwhile to describe one study in which the amount of a seasoning required for detection was determined in a side-by-side test and in a single-sample test. Samples with and without seasoning were compared. To make the single-sample test more nearly comparable with ordinary meal conditions, the sample of the food being tested and another food were presented to the judges alternately. We found that 5 to 10 times more seasoning was required for detection of the seasoning when samples were tasted singly than

when they were tasted side-by-side. This magnitude of difference may not hold for other foods differing in other ways. However, it is quite reasonable to expect that the first difference detectable under our test conditions would be considerably less than the magnitude of differences that would be noticed under ordinary eating conditions.

On the other hand, it must be recognized that levels of reduced quality doubtless exist that do not elicit complaints by the consumer but which fail to induce him to be enthusiastic about the product. Adequate information on such quality levels is not now available. Reliable tests on the relation between trained-panel results and consumer response would be very useful, provided they were sufficiently comprehensive to minimize misinterpretations.

Use of the quality change unit. This unit of change has been used to provide the following types of information:

a. Comprehensive information on relative rates of deterioration (especially temperature coefficient data) that can be used to calculate equivalent changes in quality if the temperature history of the product is known. Mr. Guadagni will describe this use of the data.

b. Information that can be used to compare in a general way the relative stability of different products. A. D. Shepherd will describe this use.

c. Information that can be used to describe the relative effectiveness of processing, packaging or other variations in treatment. D. G. Guadagni will describe this use.

d. Information that can be used to standardize chemical tests that show potential of being useful in the determination of changes. R. L. Olson will describe this use.

Recapitulation. This discussion has been presented to show the nature of the principal measure of stability used in the TTT studies conducted at this laboratory. The unit of measurement is the amount of change that makes the test sample just definitely detectable from the control by the specified procedure. This is obviously a small unit of change. It has proved very useful, as will be illustrated by other contributors to this meeting.

CALCULATION OF QUALITY CHANGE FROM TIME-TEMPERATURE RECORD

D. G. Guadagni
Western Regional Research Laboratory
USDA, Albany, Calif.

As the title of my report implies, I will discuss a procedure for the estimation of quality changes which occur as a result of exposure to variable temperature histories. We have a large amount of information on rates of quality loss at steady temperatures, but it is not particularly useful from a practical point of view unless it can be applied to the evaluation of the effects of variable temperature histories.

I am sure it is well known to you gentlemen that in handling frozen foods we are hardly ever dealing with steady temperatures. The only possible exception is the steady temperature of a properly operated warehouse. Every time we move frozen foods from one segment of the distribution system to another, we are dealing with variable temperature histories. This situation is graphically illustrated in Figure 1.

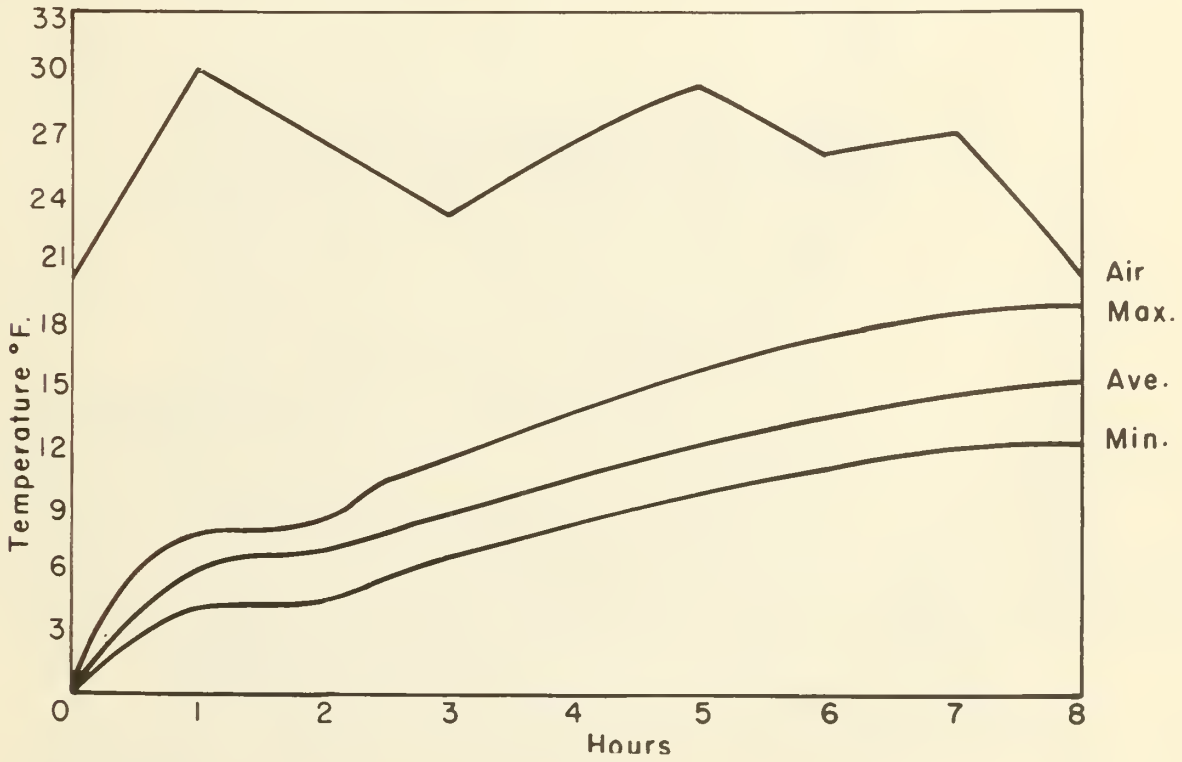


Figure 1. Product and air temperature changes in a truck during an 8-hour trip. Outside air temperature was 58 to 62°F.

The problem, then, is how to assess the effect of these variable time-temperature records that are encountered in distribution and handling of

frozen foods. One way is direct sampling and laboratory examination of the products in question. This method would require trained personnel, laboratory facilities, and considerable time and effort to make the required evaluations. The graphical integration procedure, which we are about to discuss, is much simpler and makes use of the extensive data already obtained in our time-temperature-tolerance project.

The two basic requirements of this procedure are: (a) a knowledge of the rates of quality change at steady temperatures in the temperature range of interest and (b) a temperature record of the product we are interested in. The rates of quality change for several products are available from our TTT data, and the temperature record can be obtained from a simple temperature recording device.

The first step in the procedure is to derive a smooth curve expressing the relationship between temperature and the relative rate of quality change. An example of such a curve is shown in Figure 2.

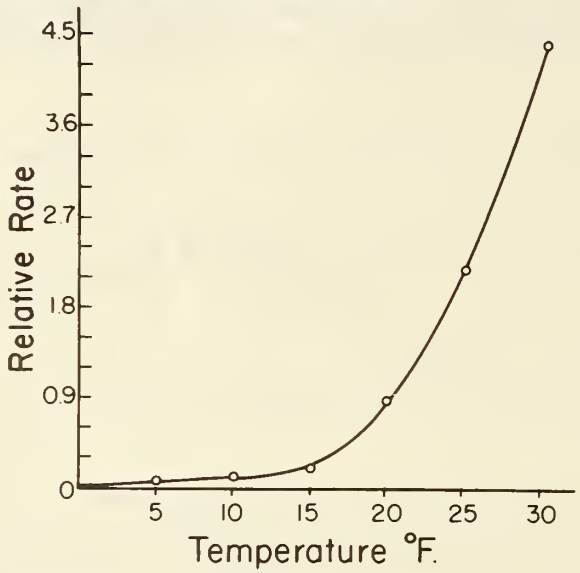


Figure 2. Relative rate of quality loss vs. temperature in frozen strawberries.

The next step is to construct from this particular smooth rate-vs.-temperature curve, a coordinate system in which the uniformly spaced horizontal axis represents time and the vertical axis is spaced in proportion to the actual rate of quality change. This is most conveniently done as shown in Figure 3.

The rate-vs.-temperature curve shown on the left-hand side is the same curve shown in the previous figure and is reproduced to show how the transformed co-ordinate system is derived and how we assign temperatures on the unequally spaced vertical axis. This spacing corresponds to the relative rates of change at particular temperatures.

The known irregular temperature history of a particular lot of frozen food is next plotted in this transformed co-ordinate system and the plotted points are connected. An example of a plot of this kind is illustrated in Figure 4.

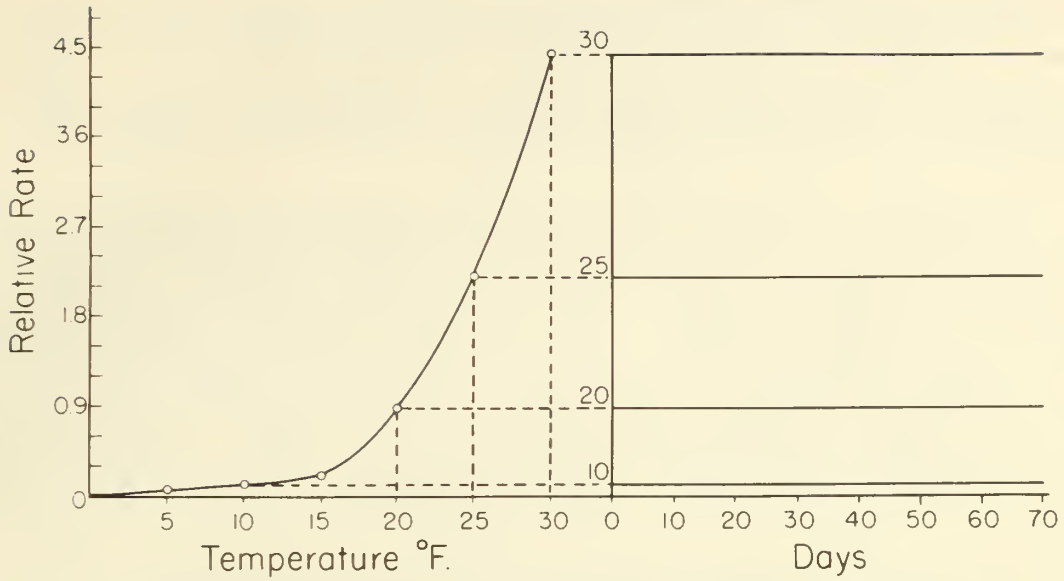


Figure 3. Coordinate system derived from rate vs. temperature.

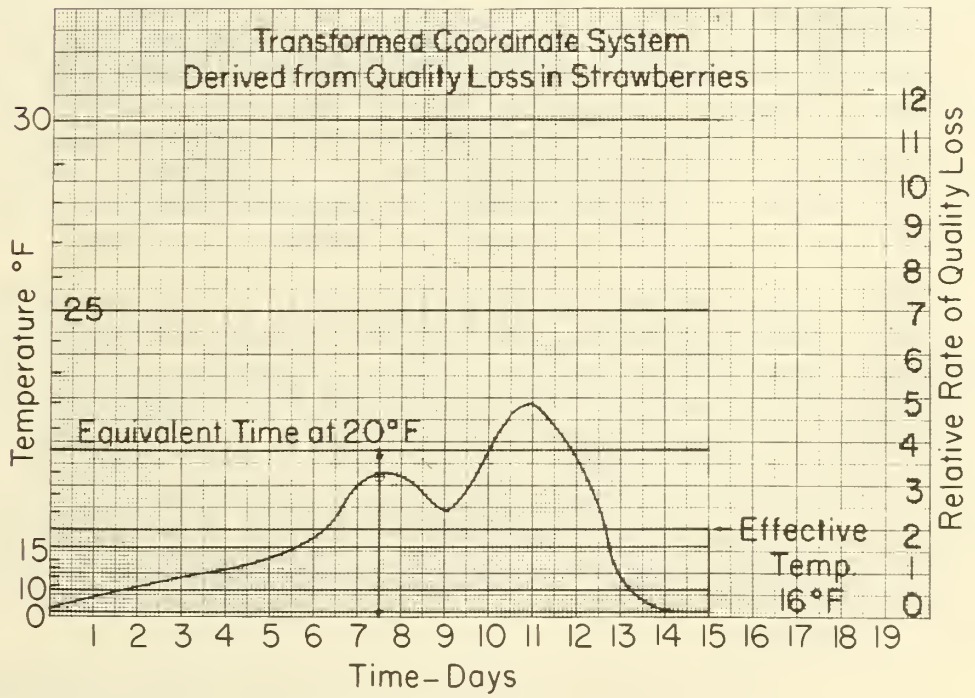


Figure 4. Transformed coordinate system derived from quality loss in strawberries.

This coordinate system was constructed by the procedure illustrated in Figure 3 on a background of uniformly spaced squares. The heavy horizontal lines superimposed on this background represent temperature in degrees Fahrenheit and each of the background squares on the horizontal axis represents time. The irregular temperature record represents temperature changes with time during shipment and subsequent cooling to 0°F.

Now we must remember that each temperature on this scale actually represents the relative rate of quality loss at that temperature and therefore we are really dealing with rates of quality change vs. time. In other words, the relative rate corresponding to the 20°F. line is 3.8 as shown on the rate scale; at 25°F. the rate is 7.0 etc. The rate of quality loss in relative units per day multiplied by time in days gives a figure which corresponds to total quality loss, just as rate of speed in miles per hour multiplied by time of travel at that speed gives a figure for total distance travelled. Therefore, the area or total number of background "squares" in this coordinate system is directly proportional to quality loss. The larger the area or total number of squares covered by any given time-temperature pattern, the greater the quality loss will be. Instead of expressing the quality change which occurs as a result of an irregular temperature pattern in terms of total quality loss or total area, it is more convenient to express it in terms of effective temperature for the duration of the experience or equivalent time at some chosen steady temperature that will produce the same change as the irregular pattern. The effective steady temperature that will produce the same change as this irregular pattern is obtained by dividing the area or number of squares under the curve by 15 days, since this is the duration of the pattern, and the area under the curve represents the summation of the products of rate multiplied by time. The quotient or result is a relative rate of change or quality loss which corresponds to the rate at 16°F., and therefore the effective temperature of this pattern is 16°F. In other words, the area of this rectangle under the 16°F. line up to a period of 15 days is equal to the area under the curve and hence the quality effects produced by these two conditions are equal.

A more convenient way of expressing the effect of the variable pattern is to divide the area under the curve by the relative rate of change which corresponds to some chosen steady reference temperature such as 20°F. The quotient in this case represents the number of days at 20°F. that will produce the same change as that produced by the irregular pattern. Here again, the area in the rectangle described by the 20°F. line and 7.5 days is equal to the area under the curve and hence the effects of the two conditions are equal. Mathematically we can prove that the two conditions produce the same effect in frozen strawberries, and experimentally we have proved that there is no significant difference in flavor or color between actual samples exposed to these two conditions.

From our steady-temperature data we know the length of time it takes a trained taste panel to detect a significant change in color or flavor of the product we are interested in. As Dr. Lineweaver has pointed out, this time interval might be referred to in terms of high quality life of the product in question. For example, a trained taste panel will find a definite color and flavor change in strawberries held at 20°F. after an average of 10 days. According to this coordinate system, 20°F. corresponds to a relative rate of

3.8, and since it takes 10 days at this temperature to produce the quality change which we have defined in terms of high quality life, 38 squares in this system represent the average high-quality life of strawberries.

Obviously, at lower temperatures the rate of change is lower and hence it takes a longer time to produce this same quality change. At 0°F. it takes about one year and at 10°F. about 2 months. It is also clear that at higher temperatures the time will be shorter, but regardless of the time-temperature combinations, an area of 38 squares in this coordinate system always corresponds to the quality change which is detectable by a trained taste panel and referred to here as the high-quality life of the product. Therefore, the area under any given irregular temperature pattern may be expressed in terms of a fraction or percentage of the 38 squares which correspond to high-quality life or in terms of number of days at a given steady temperature which will produce an equivalent change. In the example shown here, the irregular pattern has produced a change equal to that which would occur after 7.5 days at 20°F. or we can say that it has used up 75% of the high-quality life of the product.

Table 1. Equivalent effects of time and temperature encountered in distribution truck -- 8 hours' duration

Temperatures considered	Percentage loss in high-quality life (see text)			Equivalent number of days at 0°F.
	During rise in temperature	During cooling to 0°F.	Total	
Lowest temperature	0.6	1.6	2.2	8
Highest temperature	1.4	2.9	4.3	16
Average temperature	0.7	1.9	2.6	10

Now it may be of interest to give an actual example of how we can make practical use of this procedure. Product temperatures for the trip shown in Figure 1 constitute a record of changes during an actual retail delivery run in a frozen food truck here in the Bay Area. The temperature gradually increased from 0°F. to as high as 18°F. over an 8-hour period. When these temperature curves were plotted in a coordinate system such as I have shown you, it was possible to calculate the fraction of the high-quality life used up as a result of these experiences and the equivalent exposure at 0°F. that would produce the same effect. Results of these calculations are illustrated in Table 1. It is interesting to note that considering the highest temperature encountered during this delivery run, we have a loss of only 4 to 5% of the high-quality life or the equivalent of about 16 days of storage at 0°F.

I hope that in the preceding discussion and by this particular example you have obtained at least some appreciation of the value of this integration procedure in estimating quality losses encountered under variable time-temperature conditions.

RELATIVE STABILITIES OF VARIOUS FROZEN FOODS

A. D. Shepherd
Western Regional Research Laboratory
USDA, Albany, Calif.

It is my assignment to compare various frozen foods and relate them for their ability to resist change during frozen storage. In making a comparison of this sort, it is necessary to have some basis for comparison. Dr. Lineweaver has explained how we can determine the time for the first detectable change in quality. Times determined in this fashion furnish a safe basis for comparison, for if a trained panel cannot detect a difference between a test sample and a control sample, then everyone can agree that the quality has been maintained sufficiently for our purpose. Basing storage lives on this type of measure has recognizable limitations. However, time to the first detectable change is the most scientific basis yet devised for this purpose and I shall use it in making the comparisons.

Before I go further, I want to establish the nature of the frozen products with which we are dealing. The raw materials used by the frozen food industry are of necessity natural products and subject to the variability that this fact implies. Of course, we only concern ourselves with frozen products prepared from high-quality fresh material. But even when we consider only high-quality raw material, variability still remains. For example, varieties, growing area, season, and so forth, all contribute to variation. Processing adds other variables, and this subject will be dealt with by Mr. Guadagni tomorrow. I am certain that all freezers are trying to do the best job of processing that they can. However, they do use different processes and consequently variables may be introduced. Packaging may differ between processors and thus introduce more variability. I believe by now it is clear why we used many lots of commercial frozen food for our time-temperature tolerance studies at this Laboratory.

Dr. Lineweaver has told you how trained panels determine times to a first detectable change and how this is repeated using samples from the same lot stored at several different temperatures. We may plot these times to a first detectable change against the storage temperature, as shown in Figure 1. These data for strawberries are the same as Mr. Guadagni presented earlier. It appears to be different, however, because I have changed one of the coordinates. The vertical axis representing time in months is a logarithmic scale; the temperature scale is still linear. This system of coordinates is useful because the times to the first detectable change for all temperatures studied fall close to a straight line. For this product, strawberries, it makes no difference whether flavor or color is used. That is, flavor and color change at about the same rate in this whole range of temperatures. But use of a line to represent this relation is an oversimplification. Actually, not every package of frozen strawberries is represented by this line but only the average determined from many lots. If we wished to represent all strawberries, we should use a band centered along this line. You will note that at 20°F. the time for a first detectable change is about 10 days. I'll show you how we arrived at this figure.

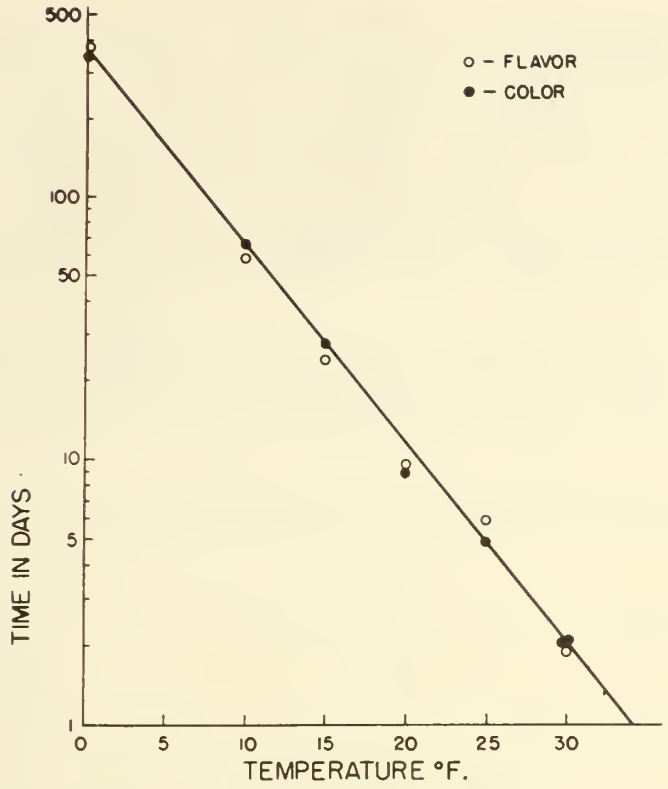


Figure 1. Effect of temperature on subjective color and flavor changes of strawberries.

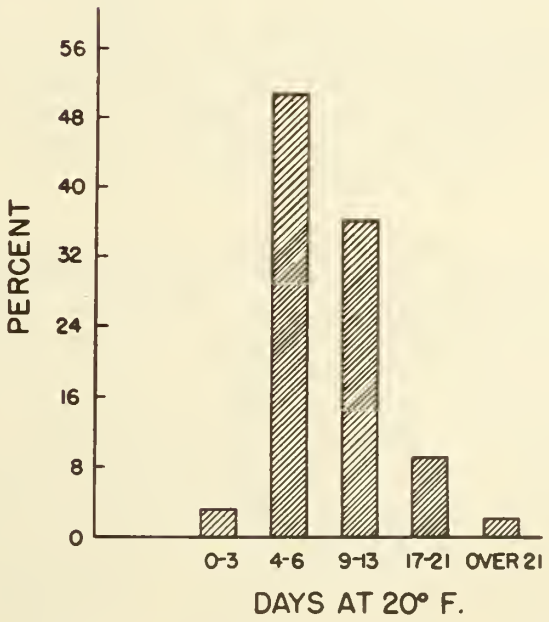


Figure 2. Percentage of total numbers of lots (55) which became significantly different in flavor from their respective controls after various storage periods at 20°F.

Figure 2 shows the spread in times actually encountered in many individual lots of strawberries stored at 20°F. Note the extreme variability represented here, all the way from 3 days or less to 21 days or more. However, only a very low percentage of samples are at the extreme and most of the samples are very much closer to the 10-day figure, which was the average that is represented in Figure 1. The variability represented here is the summation of those variables that I mentioned earlier: raw material, processing, packaging, and so forth, plus the experimental error of determining the time for the first detectable change.

In the case of strawberries, you will recall that flavor and color changed at the same time. However, for certain commodities, in particular the vegetable and poultry, the different quality attributes do not change at the same rates.

Table 1. Days to first detectable change for green beans

°F	Color	Flavor
0	101	296
10	28	94
15	15	53
20	8	30
25	4	17

Here in Table 1 are data for green beans, comparing the times for the first detectable change for color and flavor. The time determined for flavor is 3 to 4 fold greater than the time determined with color.

As a consequence, we are presented with the problem of choosing which quality attribute to use for the intercomparison of commodities. We could have selected the most critical one -- that is, the one which gives the shortest time. This seems sensible at first glance but upon further study it becomes less reasonable. If one were to choose times based on color, the lighter-colored commodities would be penalized.

It is easiest to show you what I mean by use of white paper. This piece of paper is quite acceptable as white; but when I show you another piece of paper, we can see that in reality the first piece was slightly off-white and it is likely if I searched further I could find a piece which would show that the second piece is off-white also. This shows up particularly well with whites but applies to a less extent for light colors. That is why I said "lighter colored commodities would be penalized." At this laboratory, we have studied intensively four frozen vegetables; cauliflower, green beans, peas, and spinach. Of course, cauliflower is lightest in color and do you know that judges could consistently tell a sample stored one day at 20°F. from the control - ONE DAY AT 20°F. But I don't believe anyone would be offended by the off-color or even be able to recognize a difference unless the control sample were alongside. Two weeks are required for the first detectable flavor change at the same temperature, 20°F., and it is this figure that we have used for these comparisons. Peas and green beans are deeper in color than cauliflower and show less difference between times

determined by flavor change and color change. With spinach, the darkest of them all, the deviation is reversed and the time for flavor change is shorter than for color change. Furthermore, in the early stage of color deterioration, the color remains substantially the same as that of the control except that it is dulled somewhat -- not a very noticeable change and certainly not offensive.

As a general rule, then, we have used flavor change as the factor upon which to base our times for comparison. And to have a good rule, we must have some exceptions. For poultry, the choice of quality attributes is between odor of the raw meat and flavor of the cooked meat. Here we have chosen odor of the raw meat, this being the more sensitive measure. For peaches, color change has been used, because deterioration produces a decided change in color -- from a beautiful natural peach color to an unattractive brown and is easily detected without a comparison.

Now that I have established the basis for comparison for the frozen foods, let us look at Figure 3.

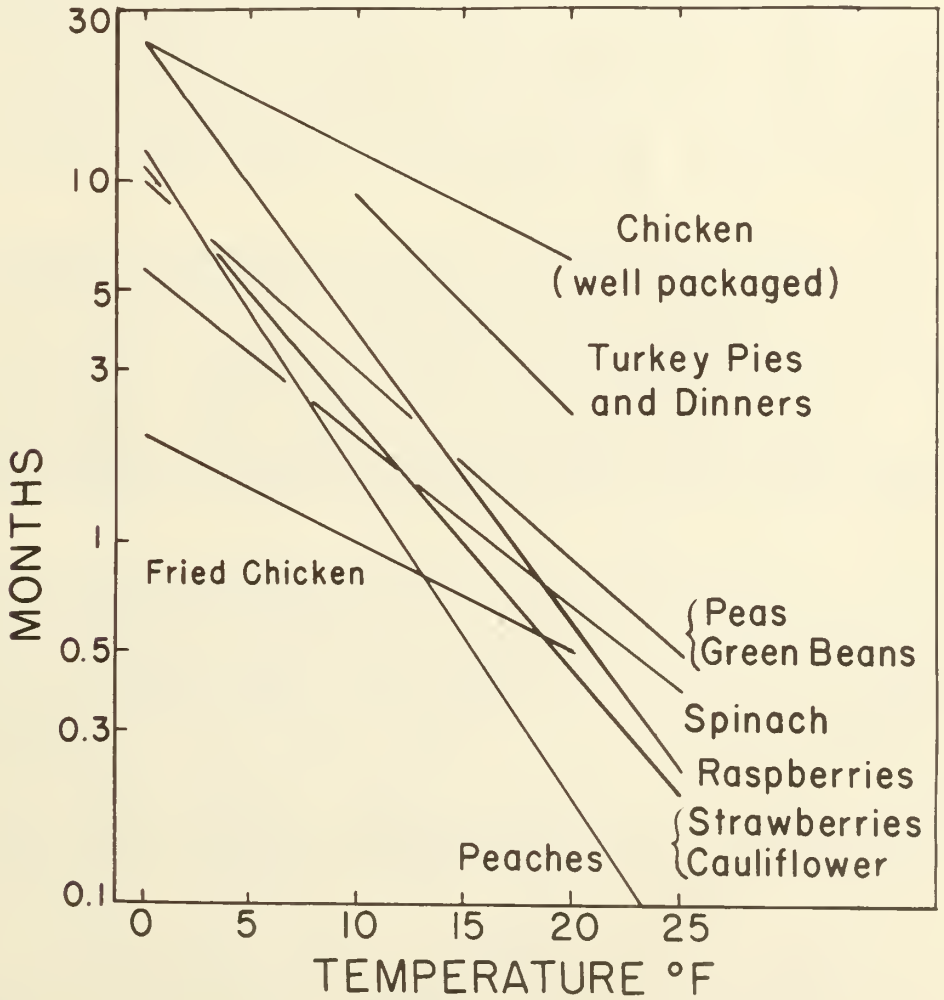


Figure 3. Relative stabilities of frozen foods.

The data represent results of research at this Laboratory only. I have grouped some commodities with very similar deterioration rates in order to simplify the graph.

The higher the line, the more stable the product. That is, the longer it takes to detect a change. So, of the products represented here, chicken is the most stable equalled at 0°F. by raspberries. Looking at the other extreme, peaches are the least stable, among commodities represented, at higher temperature but the line for fried chicken crosses the line representing peaches at about 13°F. and fried chicken becomes the least stable below that temperature.

I should like to point out the significance of the slope of these lines. Now a horizontal line would represent a product whose stability is unaffected by temperature. That is, regardless of storage temperature, that commodity would have the same storage life. Obviously this situation is never realized. On this graph chicken and fried chicken have the least slope but even they show significant temperature dependence.

Let's contrast raspberries. At 0°F. they are very stable and about equal to chicken in our terms of measuring. But the line representing raspberries has a steep slope;at +25°F. it is well down the line in terms of stability. This means that the quality of raspberries changes relatively faster than does chicken and for that matter anything else represented except peaches, which shows about an equal sensitivity to raspberries. The remainder lie between these extremes in sensitivity.

Lines are useful in representing average stabilities for commodities determined from several commercial lots. And truly what is depicted here represents difference we have found on an average. You will note that the line for chicken is qualified as well packaged. Experience with poorly packaged chicken would drop this line by a factor of about 3. This is an extreme case. But if we look at the lines for spinach, peas, and green beans, it is certain that better lots of spinach will be more stable than poorer lots of peas and green beans. As I have said before, commodities vary around these lines and a band might be a better representation.

I should like to bring into the picture the relative stabilities of frozen foods other than those studied at this Laboratory. Doing this presents problems because other researchers use a basis other than the time to first detectable change to establish the time-temperature relationship. For example, Kuprianoff, studying the storage stability of fish, uses a grading system and establishes a storage time based on the point at which the quality rating changes from excellent to very good. We think this probably represents a greater change in quality than our "first change." Professor Kuprianoff has summarized information from his work and from the work of others. Data from this summary for fish, beef, and pork are shown in Figure 4. The figures for orange juice are the findings of Dubois. You will see that I have included the lines for peaches and chicken from Figure 3. These two lines represented the extremes in that graph. Fish, both fat and lean, would seem to be less stable at very low temperatures than any commodity that we have studied with the possible exception of fried chicken. Beef and pork seem to be relatively

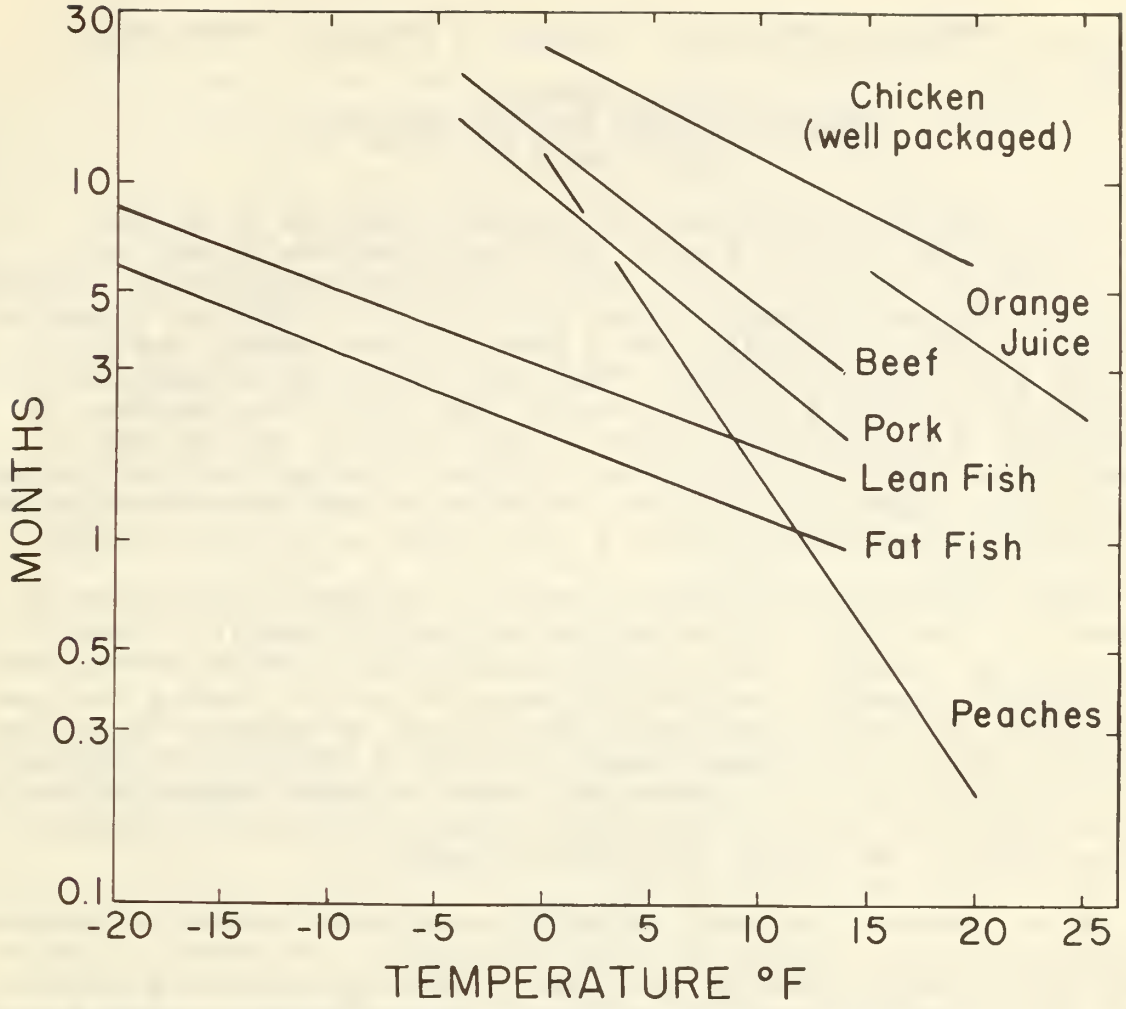


Figure 4. Relative stabilities of additional frozen foods.

stable but somewhat less so than poultry meat. And heat-treated orange juice concentrate is found in the range of the more stable frozen foods.

If we compare frozen foods with regard to stability at 0°F., we find that chicken, raspberries and probably turkey pies and dinners may be stored for well over one year without detectable quality loss. In the 10-month-to-one-year range at 0°F. before a detectable change, we find green beans, peas, strawberries, cauliflower and peaches. About 6 months produces a detectable change at 0°F. for spinach. Fried chicken requires about 6 months at 0°F.

For other products studied elsewhere, stabilities at 0°F. might be over a year for heat-treated orange juice, about 1 year for beef, 9-10 months for pork, 3 months for lean fish, and 2 months for fat fish.

From what I have shown, it is evident that not only do frozen foods differ in their stabilities when compared at a given temperature, but they also differ with respect to influence of changes in temperatures on their stabilities.

EFFECTS OF PROCESSING VARIABLES ON QUALITY OF FROZEN FOODS

D. G. Guadagni
Western Regional Research Laboratory
USDA, Albany, Calif.

It is generally recognized that freezing offers one of the best means of capturing the fresh flavor, color, and appearance of many foods. There are, however, many factors that must be carefully considered and controlled if we are to produce top-quality frozen products. For fruits and vegetables these include variety, maturity, proper handling after harvest, and proper processing and freezing procedures. Deficiency in any one of these factors is certain to result in a frozen product of less than optimum quality. By concentrating on processing variables, I certainly don't want to give the impression that other factors are not important. Nothing could be farther from the truth. However, because of limitations of time and adequate information on all of these important factors I would like to proceed as follows:

First I will briefly mention a number of processing variables which are known to affect both original quality and handling stability. Then, I will devote the remaining time to a discussion of the effect of one variable on one product -- namely, the effect of commercial pallet freezing practices on the quality of frozen strawberries. The reasons for emphasis on this one factor are: (a) It is a common commercial freezing procedure for this particular product; (b) we have a substantial amount of actual commercial data on this procedure, and (c) I believe you will readily see that it can cause definite losses in the quality of the frozen product.

As Mr. Shepherd indicated, packaging can be very important in determining stability of such products as fruits and poultry. The reason of course is that good packaging protects the product against diffusion of atmospheric oxygen, which causes rancidity or oxidation. Another closely related factor is the manner in which products are packed in the container. In certain prepared dishes where gravies or sauces are added or in fruit fillings where the fruit is covered with thickened filler, the liquid portion of the packing medium also acts to exclude oxygen from the major contents of the package and hence prolongs storage life. For example, the proper ratio of fruit to syrup and degree of container fill in frozen peaches can prolong the storage life 3 to 4 times if the product is exposed to unfavorable temperatures.

Another factor which materially affects the keeping quality of certain frozen foods is the addition of antioxidants during processing. The addition of ascorbic acid to frozen peaches has consistently demonstrated a marked improvement in both quality and storage and handling stability.

The addition of proper types of thickeners or stabilizers to prepared frozen foods can materially affect the consistency and appearance of these foods. Use of pregelatinized starches, for example, can radically alter the processing requirements for certain frozen fruit pies and materially aid in retaining the full fresh fruit flavor of these products.

Blanching or scalding is an extremely important processing variable, which applies to many frozen foods including fruits, vegetables, and poultry. The proper time-temperature relationships during blanching or scalding is every bit as important as the proper time-temperature relationships after the foods are frozen. Both color and flavor of fruits and vegetables are most importantly affected by this operation and the tenderness and appearance of poultry are certainly affected by the combined scalding and feather-removal operation. Immediately after blanching the products must be cooled, and this is another factor which can and does affect the flavor, color, and nutritive value of the frozen products. The interval between cooling, packaging, and freezing can also have an important bearing on the final quality of the products. Obviously there are many other processing variables which bear upon the final quality of the frozen product. It is difficult to assess the relative importance of all these different factors unless we have an adequate background of experimental data which pertains to each of them.

Now I will discuss one factor which is common to all frozen foods and that of course is the freezing operation. As I mentioned earlier, this will deal with a special kind of freezing -- namely, freezing cased strawberries in pallet loads rather than in individual packages on trays.

Our primary purposes in this investigation were two-fold. The first was to determine the range of freezing rates encountered in actual commercial pallet freezing operations and the second was to determine what these actual freezing rates mean in terms of quality changes. The survey on freezing rates covered 11 commercial plants located on the West Coast. The objective in each of the plants was to find the fastest, slowest, and intermediate freezing rates under actual commercial operating conditions.

Even when we try to simplify the overall problem by studying one variable at a time, many important subvariables come into the picture. One of the most important in pallet freezing is the stacking arrangement of the pallets Figure 1 shows a typical tight stack which is normal for ordinary warehouse storage after the products are frozen. You will note there is no provision for air circulation between cases. While this particular arrangement is not used during initial freezing, we have found frequent instances where pallets are restacked in this form before freezing has been completed. As we will see later, this practice very materially affects quality losses during freezing. Figure 2 shows another arrangement commonly employed in these pallet freezing operations. Here you will note that there are spaces for air through the body of the pallet but many of the cases are still stacked directly on each other, thus preventing air flow around them. Figure 3 shows another common arrangement of cases in the pallet, and here you will note that provision has been made for air circulation between tiers as well as between layers of cases. Variations of this type of stacking provide spacers between layers of cases and in certain instances the lids of cases are folded open during the freezing operation. Naturally, anything that provides for better heat transfer will give a faster freezing rate.

Now let us look at some of the freezing rate curves. Figure 4 shows some typical rates obtained in sharp freezing rooms. These rooms are normally operated at about -5 to -20°F. with little or no air circulation through or

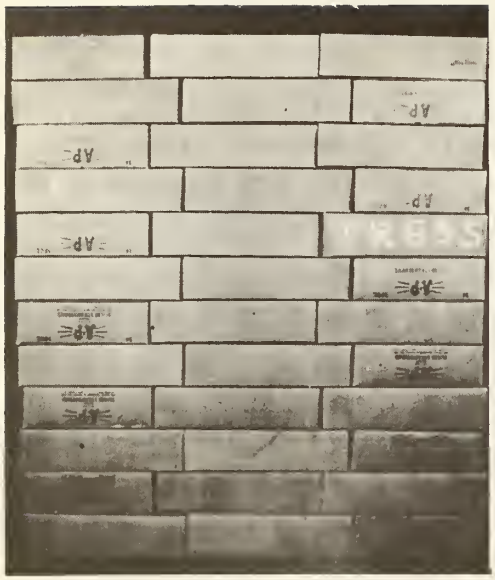


Figure 1. Tightly stacked pallet load

Figure 2. Pallet load with partial provision for air flow through the stack

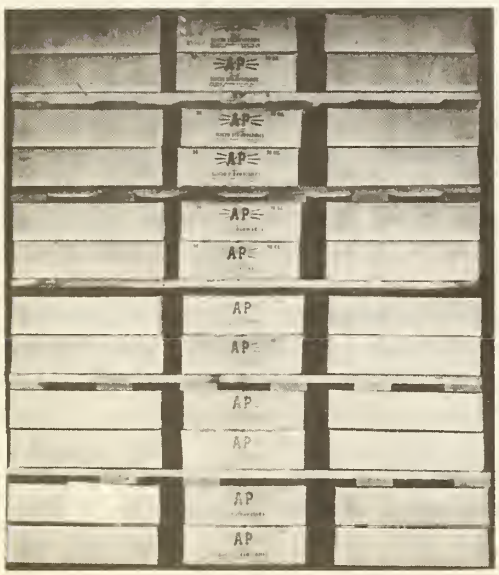


Figure 3. Provision for air flow between tiers and layers of cases.

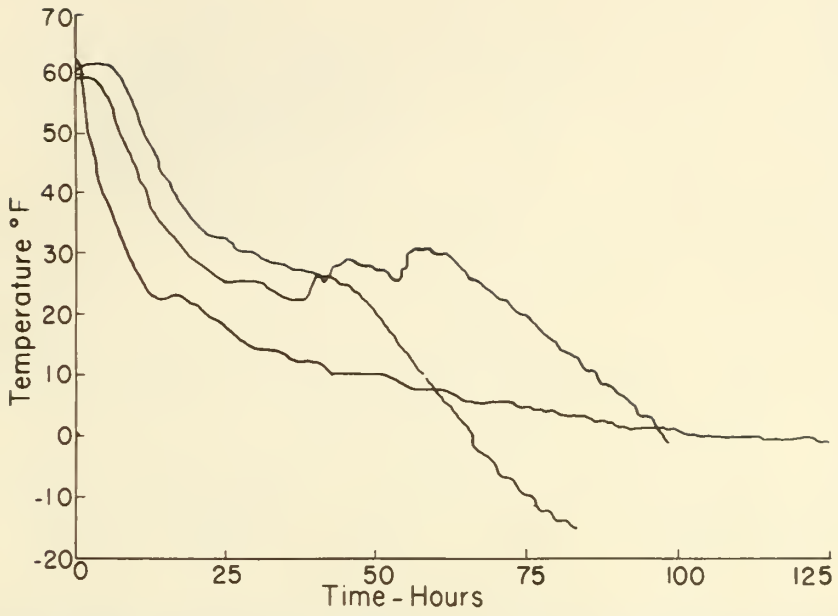


Figure 4. Freezing rates with little or no air circulation around or through pallet loads in rooms at -5° to -20°F.

around the pallets. You will note that, in general, it took about 75 to over 125 hours to bring the products down to 0°F.

Figure 5 shows the situation in one of the best operated tunnel freezers encountered in this survey. The air temperature was about -20°F. and air velocity varied from about 1100 to 2000 feet per minute. You will note that in the pallet load which was allowed to remain in this environment the product reached 0°F. in less than 20 hours, whereas the pallet which was transferred to still air storage at a relatively high temperature, required a much longer period to reach 0°F. It should also be noted that this plant used one of the best stacking arrangements encountered in the entire survey.

Now that we have seen some of the freezing rate curves and the factors which affect them, what do they mean in terms of quality changes? By means of the graphical integration procedure discussed yesterday, it was possible to evaluate each of the 75 separate freezing-rate curves obtained in this survey. The average calculated value for this entire group of rates indicated that approximately 79% of the high quality life (time required for definite color and flavor change) was being used up or lost. This is roughly equivalent to 9 to 10 months' storage at 0°F. since our definition of high quality life corresponds to about one year at 0°F. for strawberries. Figure 6 shows the extremes found for the entire survey, and the percentages assigned to each rate curve refer to the percentage of high-quality life lost or used up as a result of that particular rate. The fastest rate caused a quality change equivalent to about one-fourth of the high-quality life or 3 months of storage at 0°F. The slowest curve, on the other hand, caused a loss of 200 per cent

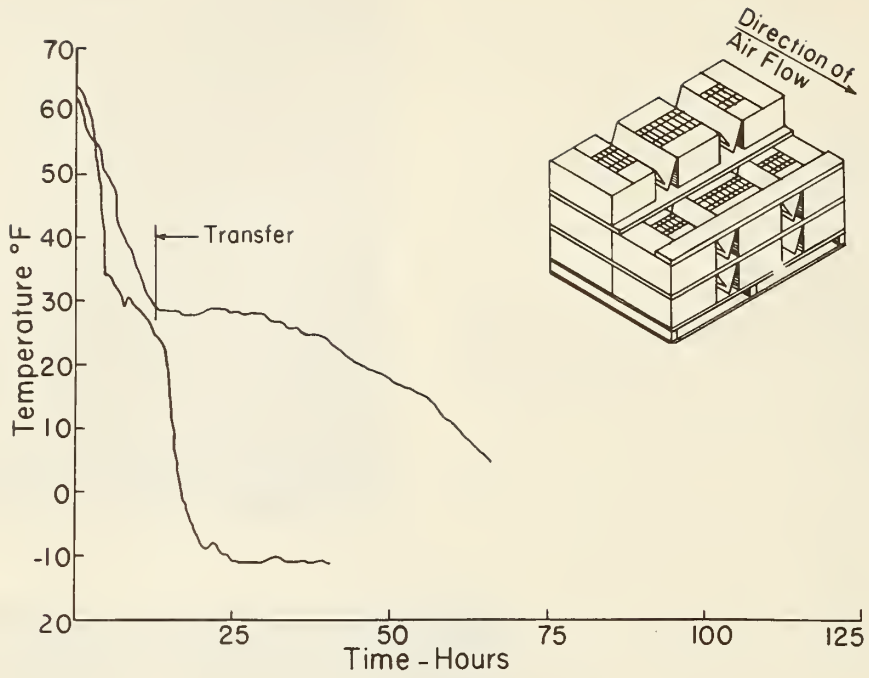


Figure 5. Freezing rates in tunnel freezers at about -20°F. with air velocity varied from about 1100 to 2000 feet per minute

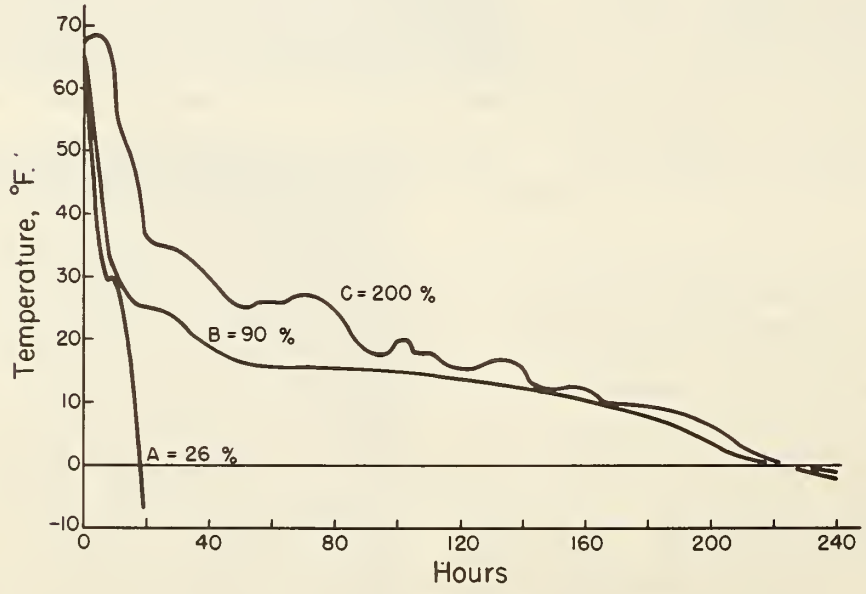


Figure 6. Extremes of freezing rates found in the survey of operations

of the high-quality life or the equivalent of 2 years of storage at 0°F. In other words, the product in this particular pallet load was already the equivalent of 2 years old the minute it first reached 0°F. Even though the time to reach 0°F. was about the same for both curves B and C, Curve C caused over twice the quality loss found in curve B. The simple reason for this big difference in quality loss is the difference in time between the two curves in the higher temperature ranges where quality is lost very rapidly. This illustrates the importance of knowing the nature of the entire freezing-rate curve rather than just the total time to reach a given temperature.

Now we might wonder why there is so much variation in quality loss between the best and poorest rates found in actual practice -- that is, almost an 8-fold variation covering all 11 plants. Even within a given plant, we have found as much as a 3-fold variation from the best to poorest rate. Since these results were obtained in commercial plants, using different equipment of various kinds, different procedures, etc., there are probably many variables which account for the observed differences. However, I believe we can boil all these down to 3 basic factors and these are:

(a) air temperature of the freezer, (b) air velocity in the tunnel, and (c) stacking arrangement.

Actually all three of these variables are closely interrelated. For example, if you have a tight stack arrangement, no matter how low the air temperature or how high the air velocity, the center cases will not have the benefit of these good environmental conditions.

Throughout this entire survey, the greatest quality losses were always encountered in the plants which removed pallets from the freezer before freezing was completed and restacked for storage in still air. Results of such a practice in terms of quality loss are illustrated in Table 1.

Table 1. Effect of pallet transfer at various center-case temperatures

Temperature °F.	Percentage of high-quality life lost (see text) if -- Transferred to still air at 0°F.	Allowed to remain in blast freezer
30	62	11
25	42	3
20	18	1
15	2	Less than 1

Here you can readily see the large increase in quality loss which occurs when the product is transferred from blast freezer to still air. From a quality standpoint there is a tremendous advantage in leaving the product in the blast freezer until it reaches at least 15°F. Thereafter the advantage is very small or insignificant.

From this brief discussion I hope you have gained the impression that many factors besides time and temperature in the distribution system can affect the quality of frozen foods, and even when we consider a single factor such as we have here today, many derivative variables come into play in determining the importance of the overall variables.

OBJECTIVE TESTS FOR FROZEN FOOD QUALITY

Robert L. Olson
Western Regional Research Laboratory
USDA, Albany, California

In the previous presentations a number of factors affecting the quality retention of frozen foods have been discussed. With a few exceptions, examples were given in which the quality retention had been judged by organoleptic or sensory evaluation. It was one aim of the TTT research program to use chemical or physical measurements to supplement the sensory tests where suitable methods were available. Of course, it is recognized that the quality attributes of commercial interest are based on sensory perceptions. On the other hand, subjective evaluations are very costly, difficult to interpret, and not always as reproducible as we would like. Ideally, a chemical or physical measurement is sought that will correlate so well with subjective evaluations that, after establishment of the basic correlation, it may be used almost to the exclusion of further testing by response to flavor, color, or textural values. The ideal has not been reached. However, within certain limits, objective measurements have been selected or developed, tested for correlation with test panel results, and found to be very useful in the continuing research on quality maintenance of frozen foods.

The need for even better methods for measuring frozen food quality is implied in some of the suggested codes on handling frozen foods. For example, in the following statement:

> "Lots /of frozen foods/ with an internal product temperature in excess of 0°F.../shall be/ detained from sale...pending chemical, bacteriological, and organoleptic examination...to determine whether or not a loss in quality condition and grade has occurred. Laboratory findings shall be used to determine a proper disposition of such products."

In this presentation I shall discuss the most promising of the objective measurements used in the course of our investigations. It is possible to say at the outset that chemical and physical measurements have been of extreme value in the research work and some could be useful in establishing industry standards if such were desirable. Unfortunately, it must also be said that none of them show immediate promise for use in the enforcement of frozen food handling codes or in litigation that might come about by detention of merchandise from sale. At best they may provide some presumptive evidence that could lead back to correction of abusive handling if it were a continuing malpractice.

Six of the objective tests used in the TTT studies will be mentioned. These involve: (a) chlorophyll degradation, (b) ascorbic acid oxidation, (c) soluble color components, (d) transfer of soluble components, (e) chemical indication of fat rancidity, and (f) reflectance color measurement.

Measurement of chlorophyll degradation in frozen green vegetables. Color quality of processed green vegetables is dependent on the preservation of chlorophyll. As chlorophyll is changed to the olive-brown pigment, pheophytin, the bright, garden-fresh vegetable color is lost and replaced by the dull or dark-green that is typical of badly overcooked greens. Generally speaking, all the green pigment of living plants is chlorophyll. If reasonable care is taken following harvest, no significant changes take place during any delay between harvest and processing. As the plant is killed by the processing treatment, a small or substantial portion of the chlorophyll may be converted into pheophytin; then in subsequent storage, change continues in the preserved vegetables.

The conversion of chlorophyll to pheophytin is a chemical reaction and the reaction rate, whether during processing or subsequent storage, is largely dependent on the product temperature. In the laboratory, the chlorophyll change can be measured as a ratio of pheophytin to chlorophyll and the results expressed as the percentage of original chlorophyll that has been retained. Two important features of the method are that (a) it is not necessary to know the concentration of pigment, only the ratio of the components, and (b) we know what was the initial chemical quality -- that is, all of the pigment was chlorophyll to start with. Both factors are important and although I will not now go into the details of the first one, I will say something more about the latter one.

In the investigations we are discussing, the most useful measurements are concerned with change. Thus, you have heard much about the time required for a change to be large enough so that it can be detected. For such judgments there is needed a "before" and "after" sample. For green vegetables, we can tell how much change has occurred without the "before" sample, because we know all the green pigment was chlorophyll prior to processing. It follows that all the pheophytin we can measure represents change in chemical quality. We can call this zero point a "bench mark," analogous to the bench mark a surveyor would use to orient his position. The most useful analytical methods, then, are those with a built-in bench mark and we need not have a protected sample for comparison.

The following series of illustrations indicate how chemical change in chlorophyll follows the time-temperature experiences of green peas and snap beans.

Figure 1 shows the experimental record of chlorophyll loss for a lot of frozen peas when subjected to several different storage temperatures. The points indicated are the means of duplicate analyses and are found to be quite close to the calculated regression lines. In other words, we are confident that by making only two analyses of the chlorophyll retention of frozen peas, we can tell, rather precisely, what percentage of the original chlorophyll has been converted to pheophytin. The effect of storage temperature is portrayed. The change is measurable but hardly significant at 0°F. For each 10 degrees of increase in storage temperature, about a four-fold increase in deterioration rate may be seen. In a side-by-side comparison our panels can detect a color change between samples of frozen peas differing by about 1 1/2 per cent in the amount of chlorophyll retained. No evidence was obtained to tell how

how much more change would be required if samples were to be distinguished as different without the direct comparison. I would say that the factor of 5 to 10 that Dr. Lineweaver found to apply in the seasoning experiment would be of the right order.

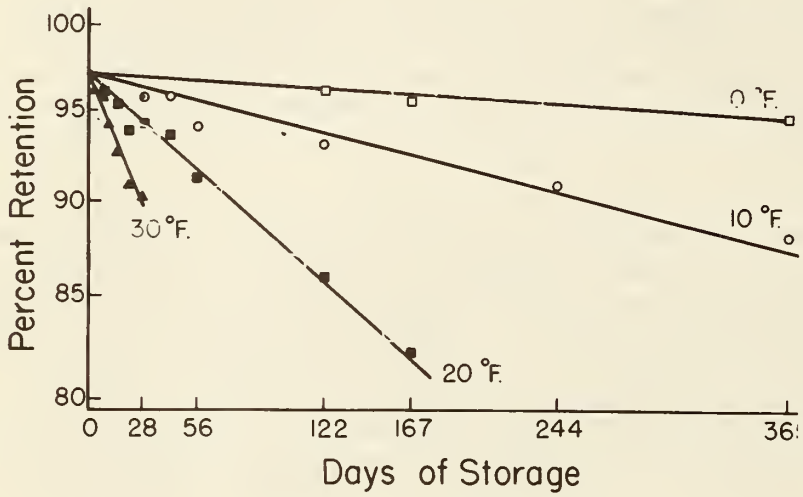


Figure 1. Effect of temperature on chlorophyll retention in peas.

You will note that there was not 100 per cent of chlorophyll at the start of the storage tests, because about 3 per cent of the chlorophyll was converted during the processing. This is very important because all frozen peas have not been subjected to the same processing conditions and consequently do not start at the same point. In Figure 2 the 20°F. line from Figure 1 is shown with 20°F. lines from three other lots of frozen peas. You will note that the loss of chlorophyll during processing is different and that in the worst instance, about seven per cent of the original chlorophyll was lost before the storage phase began. Differences exist among these commercial lots because the industry has not standardized its processing methods. It is appropriate here to mention that if it were considered desirable, a measurement of this type could be used by a factor in the frozen food industry to control quality of his product. It might be useful, at some future stage of development, as an industry standard for quality of frozen green vegetables. If a standard for marketing frozen peas were set at 85 per cent, the first lot could be held for 4 months at 20° before all the marketable quality would be dissipated. The fourth lot will stand less than one-half that time-temperature experience.

The effect is even more striking in our observations of frozen green snap beans. Figure 3 presents data on six lots of beans. (Let me reiterate that all of these frozen food data are from commercial packs.) The processing differences of these lots accounted for losses of the original chlorophyll ranging from 5 to 30 per cent. Again, if a quality standard were selected (this time at about 60 per cent because the relationship between chlorophyll-pheophytin ratio and color quality is not the same for beans as for peas), one sees the poorest lot has been reduced to the standard in three weeks at 20°F. while the best is not half way there after two months.

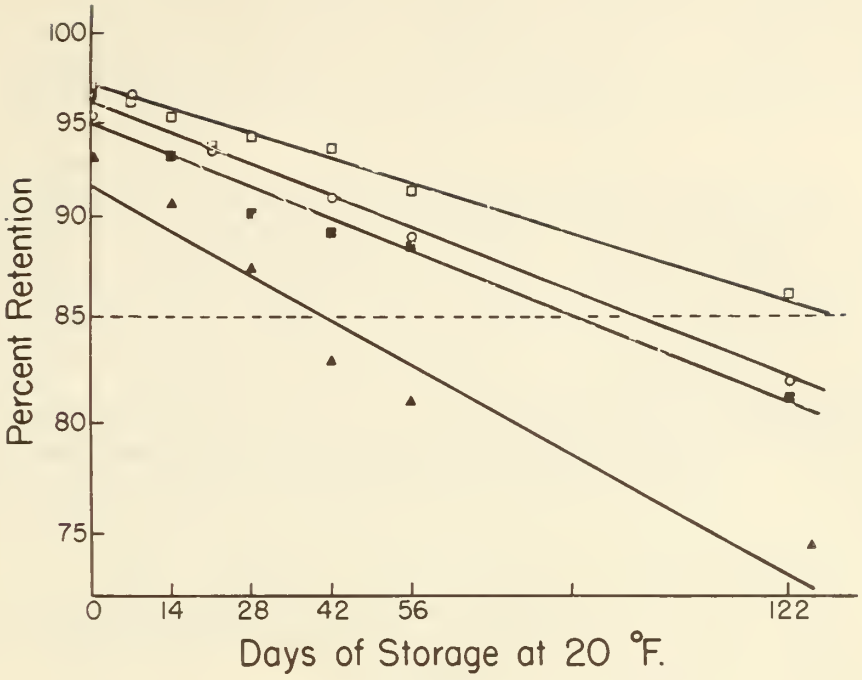


Figure 2. Chlorophyll retention in peas.

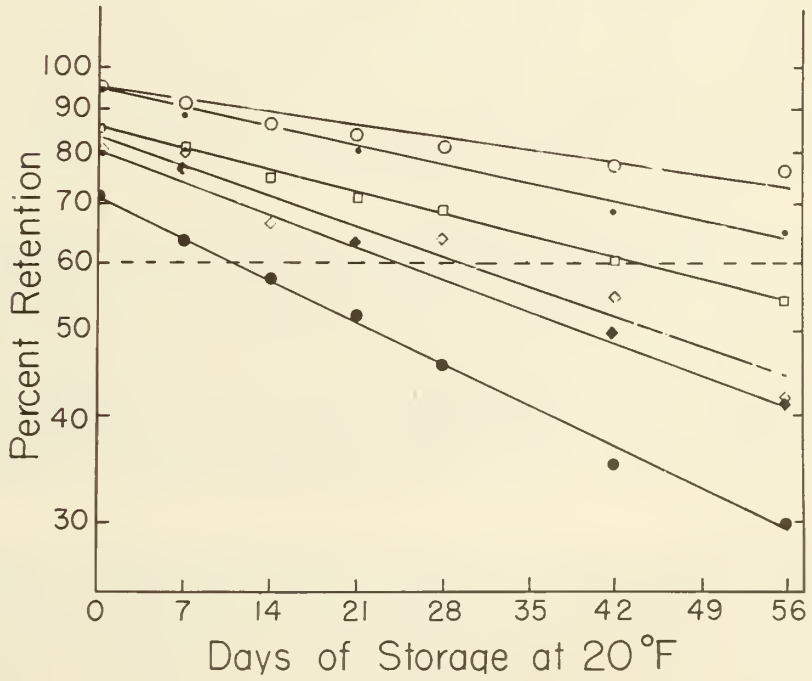


Figure 3. Chlorophyll retention in green beans.

Because of the precision of these chemical measurements, it was possible to trace the initial processing loss directly to the blanching procedure used, and also to discover that a poor blanching operation had a compounding effect of both destroying color quality during processing and enhancing the rate of subsequent deterioration during storage.

Useful as the measurement of chlorophyll is, the method has its limitations. For example, to go back to the handling code that I quoted with regard to detention of a frozen food if its temperature is found to be above 0°F. Samples would be sent to a laboratory where chlorophyll-pheophytin ratio could be determined. Just imagine that it was found that 75 per cent of the original chlorophyll was still unconverted in a detained lot of beans. On the basis of our experience this could be interpreted over this broad range of past history:

(a) The sample was processed so as to have retained 95 per cent of its chlorophyll throughout its processing, has undergone the equivalent of 50 days at 20°F., and is expected to withstand 45 more days at an equivalent of 20°F. before the chlorophyll will be further reduced to 60 per cent, or

(b) The sample was processed to have retained 75 per cent of its chlorophyll, has not undergone measurable storage deterioration, but is expected to withstand only 20 days at 20°F. before the chlorophyll is reduced to 60 per cent.

Thus, in the absence of information on the past history of these green vegetables, the measurement of chlorophyll loss cannot be interpreted so as to tell whether or not some mishandling has occurred. The changes caused by mishandling are as yet indistinguishable from those representing a widely variable quality condition that is related to existing processing differences in the frozen food trade. Such a lot-to-lot variability will remain a stumbling block to use of objective quality measurement as long as industry practice remains unstandardized.

If industry processing techniques were standardized to the point that no lot of beans would be produced with less than 85 per cent of the original chlorophyll converted, then the situation cited above could be interpreted as follows:

(c) The sample found to have 75 per cent of its original chlorophyll will be known to have experienced at least the equivalent of 18 days at 20°F. (or nearly a year at 0°F.) and it will withstand at least 30 days more at 20°F. before the chlorophyll level will deteriorate to 60 per cent.

Under such circumstances, the chlorophyll measurement would be generally useful as a quality index. As it stands now it could be a useful index for voluntary control of product quality by members of industry who develop background information on packer processes or who can pursue the identity of product lots through the marketing channels.

It might be added that the method is not as simple as we would like to have it. To determine chlorophyll-pheophytin ratio requires rather expensive laboratory equipment and probably a professional chemist, rather than a

technician, to maintain the equipment and supervise the analytical work. We have carried out an investigation of the methodology (by contract research at Brigham Young University) and are doing some work in continuation of that project. We have improved our research technique but still do not have a method that would be equivalent in its simplicity, for example, to the test for peroxidase inactivation which is widely used in the frozen food industry.

Measurement of ascorbic acid and its oxidation products. Most frozen fruits and vegetables have a certain amount of ascorbic acid, a compound identified with vitamin C activity. Furthermore, ascorbic acid in its reduced form (as it exists in live plant material) is measured rather easily and has long been used in scientific investigations as an indicator of food quality deterioration with storage. In the presence of oxygen, ascorbic acid is oxidized to dehydroascorbic acid (DHA), which changes to diketogulonic acid (DKA). These reactions are temperature sensitive also and may thus be used to measure quality change that is related to time-temperature experiences in the handling of frozen foods.

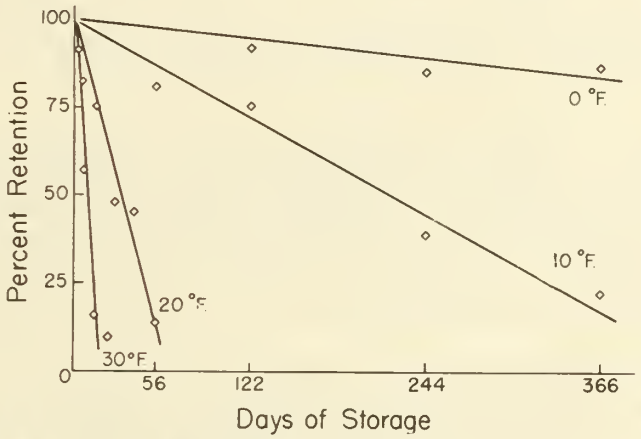


Figure 4. Effect of temperature on ascorbic acid retention in peas.

Deterioration of reduced ascorbic acid for peas is shown at four temperatures, Figure 4. In our studies of peas we encountered lots ranging from 13 to 25 mg. per 100 grams. Such a wide variation in the initial level of ascorbic acid makes it very difficult if not impossible to interpret the meaning of the reduced ascorbic acid level of a sample lot of peas taken with an unknown background from the marketing channels. For ascorbic acid content of peas, there is no bench mark of initial or original chemical quality, parallel to the chlorophyll measurement.

On the other hand an interesting thing has been discovered about frozen strawberries. If one analyzes not only for the reduced ascorbic acid but also for the DHA and DKA, such a bench mark of original chemical quality can be derived. Figure 5 gives an example. A lot of strawberries, stored 120 days at 20°F., was tested at intervals. The sum of the three compounds tested for remained substantially equal over the entire interval. It may be seen that if such a lot of strawberries had been detained in trade channels and submitted to test, it would be possible to ascertain what its original ascorbic acid concentration had been and how much deterioration had occurred since the berries had been harvested. Again, you can estimate how useful such measurements would

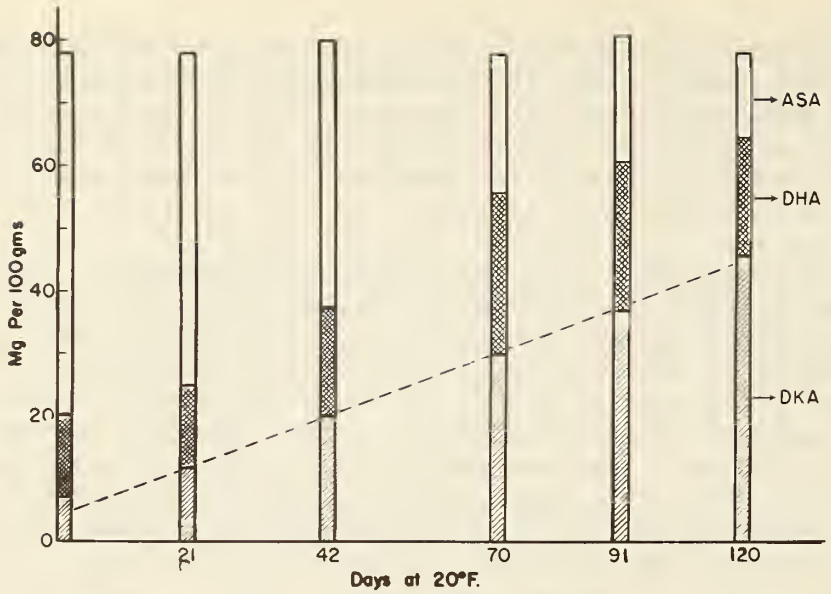


Figure 5. Changes in proportions of reduced ascorbic and dehydroascorbic acid, and diketogulonic acid in strawberries during 120 days at 20°F

be to someone carrying out a research program or someone who had some knowledge of the past history of the lot under observation. However, it is not possible, with existing knowledge, to determine whether a lot of strawberries has concentrations of these products (as seen in any one of the bars on the chart) because it was shipped or stored at a high temperature or because it had been frozen too slowly by the processor, as was discussed earlier today.

In none of the objective measurements we have used is it possible to distinguish between chemical change that is caused by processing and that caused by handling abuse. Furthermore, other products tested for the oxidation compounds of reduced ascorbic acid do not give even as good a picture as strawberries. Figure 6 shows cauliflower, peas, and beans. In all three products, the sum of the three compounds is not constant, and the method does not provide the desired bench mark of original quality. In addition, the initial level of reduced ascorbic acid in peas and beans is so low as to make the measurement somewhat questionable in value anyway. The other fruits studied, cherries, raspberries, and peaches, also have a low initial ascorbic acid level, but do have constant sums of the three compounds. The story about peaches is further confounded by the nonstandardized ascorbic-acid additions in the syrup in order to reduce the tendency of the product to turn brown.

Because there is substantially no DKA in the original products as harvested, it is possible that this one compound might be a useful indicator of quality in stored frozen vegetables. In this instance, 0 mg. per 100 grams would be the bench mark of initial chemical quality. Figure 7 provides some information on three vegetables. After two months at 20°F. peas and beans have **not** developed enough DKA to provide a useful quality index while two lots of cauliflower show a variability that would make the compound rather useless in the establishment of the past handling experiences that any particular lot of cauliflower might have been subjected to.

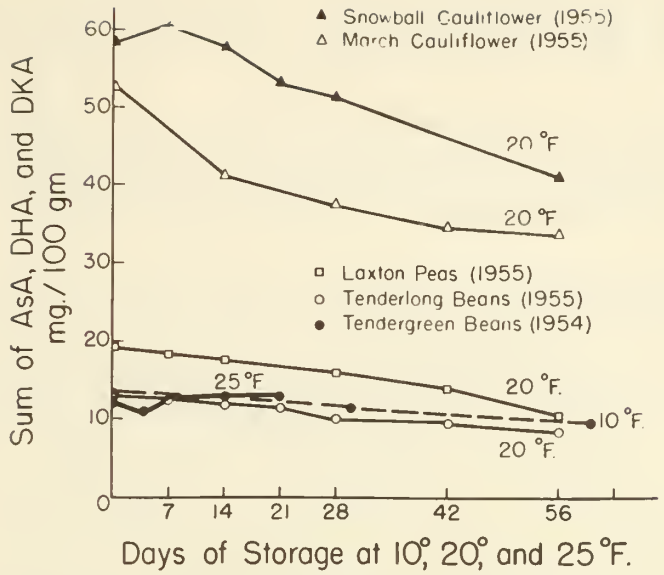


Figure 6. Oxidation products of reduced ascorbic acid in cauliflower, peas, and green beans held at various temperatures.

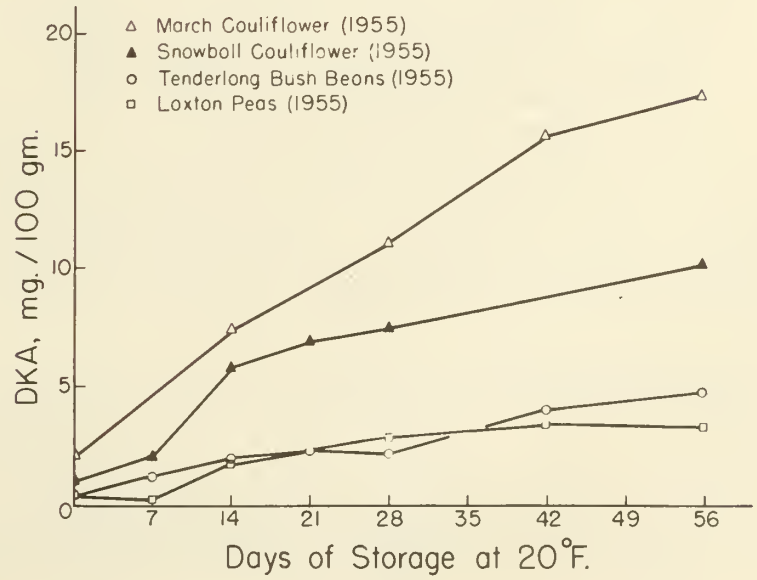


Figure 7. Development of diketogulonic acid in cauliflower, peas, and green beans held at 20°F.

Before discussing other objective measurements of frozen food quality in connection with changes in frozen foods related to handling practices, it may be said that despite the weaknesses mentioned, chlorophyll deterioration and ascorbic acid oxidation are measurable chemical changes that rather accurately follow quality deterioration, and have been found to correlate well with changes in aesthetic quality attributes.

The other objective measurements that have been used in this investigation will be discussed with brevity. Each has been useful in the research phases and some may have a limited commercial application under special circumstances in frozen food handling.

Soluble color components. For cauliflower a change in color is caused by the time-temperature history experienced by the product. The water-acetone-soluble brown pigments of cauliflower can be measured by photocolorimeter or spectrophotometer to obtain useful data on quality change. It has not been found that this method provides the built-in bench mark necessary to establish what was the original quality of a sample being measured, nor is it independent of product variability so generally encountered. So far its use has been limited to situations where some history is available of the sample under investigation.

Transfer of soluble components. In frozen fruit packed with syrup an equilibrium phenomenon was useful in evaluating the history that products may have been subjected to. As packed, these products have a difference in composition between the pieces of fruit and the syrup. For example, the syrup has a higher sugar content than the fruit and has none of the natural fruit components. As the product is stored for long periods there is a transfer of components to achieve an equilibrium condition. Thus, the fruit pigments will enter the syrup and the sugar will enter the fruit (or will draw water from the fruit to dilute the syrup). Such changes take place to an extremely limited extent at 0°F. but increase very rapidly as the temperature increases toward the melting point. The equilibrium is reached so rapidly at the melting point, or above it, than when one finds that the sugar content of the fruit and syrup are equal it is almost certain that the product has been thawed or been subjected to rather severe history. This then can be a thaw indicator. Increasing red color in syrup drained from frozen cherries and raspberries can be measured by photocolorimeter to evaluate degree of time-temperature experience. Figure 8 shows the effect of time and temperature on the soluble solids distribution in frozen RSP cherries. Very little change is indicated at 0°F., more at 20°F., and rapid equilibration at 30°F. Figure 9 shows equilibration of color for the same product at 20°F.

Chemical indication of fat rancidity. Frozen poultry products are subject to rancidity development during storage. An obvious chemical measurement in such instances is that of peroxide value. It was found that peroxide value of various parts of poultry products did increase with time and temperature. However, the correlation of peroxide value with subjective indication of rancidity was too imperfect to be useful for measuring quality of these products over the range that was appropriate for this research program.

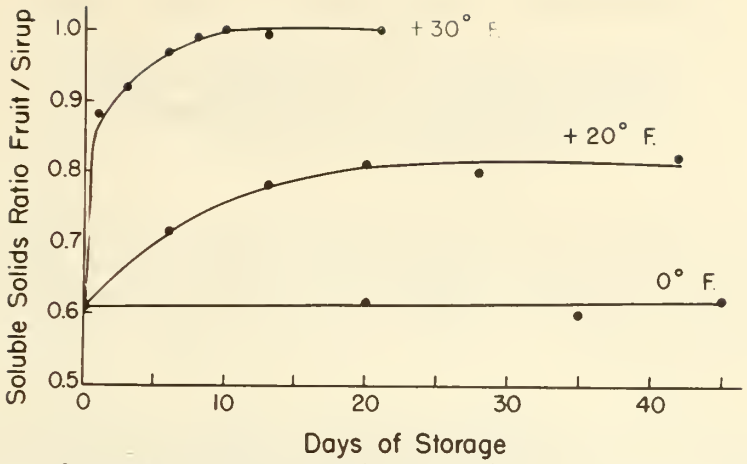


Figure 8. Effect of temperature on soluble solids distribution in red sour pitted cherries held at various temperatures.

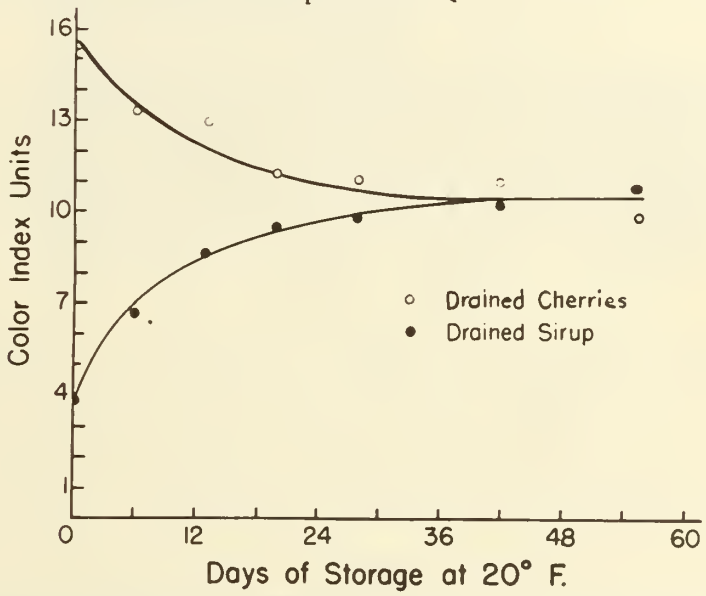


Figure 9. Color distribution in syrup-packed red sour cherries held at 20°F

Reflectance color measurement. For experimental studies where control samples can be set aside for later direct comparisons or where the history of deterioration is followed at intervals, the physical measurement of color by reflectance gives useful data. The Hunter Color and Color Difference Meter or the Gardiner instrument have been used to a considerable extent in these investigations. As with other measurements the results were subject to considerable lot-to-lot variability and there could be established no bench mark of initial quality.

Summary. In summation, there are useful objective chemical and physical methods by which quality of frozen foods can be measured. Such methods have good value in obtaining a better understanding of the nature of quality change and factors that affect change. Under current trade practice they might have some limited value in controlling product quality and handling techniques, but they do not appear to be sufficiently advanced to be of value in the regulation of commercial handling practices of frozen foods.

REVIEW OF THE MICROBIOLOGY OF FROZEN FOODS

R. Paul Elliott and H. David Michener
Western Regional Research Laboratory
USDA, Albany, California

This is a preliminary report on an extensive survey of the literature on the microbiology of chilled and frozen foods. It was undertaken primarily to give the food industry and law-enforcement groups a reference work showing the importance as well as the limitations of microbiology in questions of quality and safety in frozen foods.

The survey includes a study of both frozen and chilled foods, with a limitation of 40° F. as maximum temperature. Today's presentation will be limited to frozen foods, except for a few instances where we dip into the chilled food field to prove a point.

We will first describe safety aspects of frozen-food microbiology, including growth, toxin formation, and survival of food-poisoning bacteria at low temperatures. Then we will touch on fecal indicators in a similar manner, and then the minimum growth temperatures of psychrophilic organisms. Our next field will be the growth of psychrophilic organisms at low temperatures, and finally we will summarize arguments we have found for and against microbiological standards.

In a field as large as this we were forced to limit our scope. We have omitted the subject of sanitation, except as it applies to other aspects of the study. We have omitted several other fields too, because they have been reviewed elsewhere. For example, milk products have been covered only partially; analytical methods, and products of bacterial metabolism in food, chemical preservatives and irradiation have been omitted. We will publish the full review, including a comprehensive list of references, as soon as possible.

Dangers from food-poisoning organisms at low temperatures. For purposes of today's presentation, when we speak of food-poisoning organisms we mean to include both those that produce toxins, that is, Clostridium botulinum, Staphylococcus aureus, and Clostridium perfringens, and those that cause food infections, such as Salmonella. Fortunately for the frozen and chilled food industries, we have found no reports of food-poisoning bacteria that can grow at temperatures below 40°F. Figure 1 demonstrates this graphically. Although growth of food poisoning bacteria at temperatures below 40° F. has not been reported, psychrophiles can grow at much lower temperatures. This means there is a temperature zone above and below the freezing point where spoilage can occur without production of toxicity or infectious doses of microorganisms.

This has some significance for the food industry. Before Clostridium botulinum can produce its toxin, it must grow. It has never been reported to grow below 40° F. Before Staphylococcus aureus can cause toxicity it must grow to large numbers. It has never been reported to grow below 40° F. Usually, the salmonellae will not cause infections unless they are present in large numbers. (There have been occasional exceptions.) In any case, growth of salmonellae below 40° F. has not been reported.

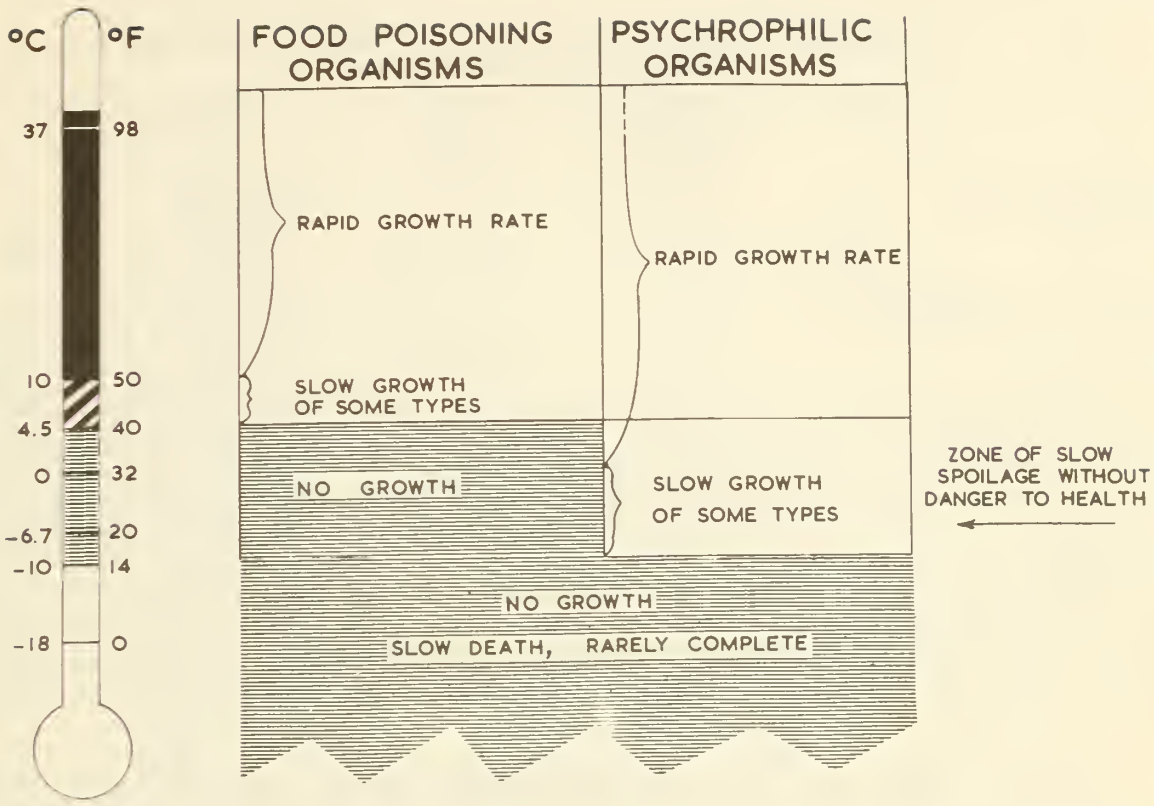


Figure 1. The temperature range of growth of food poisoning and psychrophilic organisms.

The food-poisoning organisms, even though they do not grow at low temperatures, do survive chilling and freezing. The question of survival will be taken up in detail later on.

This means that so far as frozen food is concerned, the danger from food poisoning lies in the grossly mishandled product, whether mishandled before freezing by the packer, during distribution, or in the hands of the housewife. As you know, the bland, neutral, precooked foods offer the best opportunities for bacterial growth. Several investigators have shown that incubation of some of these products at or above room temperature can cause formation of toxins from clostridia or staphylococci, or infectious doses of salmonellae. These organisms are often present in small numbers in our foods. Some authors have said that their presence is often unavoidable. Unless the product is allowed to incubate at temperatures above 40° F. they will ordinarily do no harm.

Fecal indicators. On the other hand, some of the fecal indicators can grow at lower temperatures than can the food poisoning bacteria. Note in Table 1 that Aerobacter aerogenes and enterococci have been reported to grow at 32° F. Aerobacter aerogenes is one of the members of the coliform group; this means that the coliform group and the enterococci if present initially in small numbers can grow in certain chilled foods to large numbers; but these numbers would

not necessarily represent recent fecal pollution. E. coli, on the other hand, grew at 46.4 but not at 43° F.

Table 1. Minimum temperatures for growth of fecal indicators (representative data)

Species or group	Growth at (°F.)	No growth at (°F.)	Reference
Escherichia coli	46.4	43	Ingraham, 1958
Coliforms	39 to 43	30 to 32	Wilson & McCleskey, 1951
Aerobacter aerogenes	41 to 43	37	Orla-Jensen, 1919
	32		Greene & Jezeski, 1954
Enterococci	50	40	Gibbons et al., 1944
	32		Foter & Rahn, 1936

In frozen foods, the question of survival of fecal indicators becomes the important one. Bacterial survival will be discussed in detail a little later. It suffices to say that E. coli does not survive freezing as long as the coliform group, which in turn does not survive as long as the enterococci. E. coli dies at more nearly the same rate as some of the salmonellae, and thus may be a better indicator of potential danger from such organisms. But the enterococci survive longer to indicate an esthetically bad insanitary practice in handling before freezing.

Survival of microorganisms at freezing temperatures. In discussing the survival of microorganisms at low temperatures, we should first consider what happens to them at the time they are frozen. If a suspension of microorganisms is frozen and viable counts are made on it within a few hours, it is usually found that the count has dropped far below the initial count. The percentage of survival commonly varies with the organism. It also varies with environmental factors, such as the pH and chemical composition of the substrate. For example, survival of a yeast was 37 percent in water and 88 percent in a 30 percent sucrose solution. Gelatin and the constituents of ice cream exert similar protective action. Peel oil (100 ppm.) reduced survival in orange concentrate from 8 to 0.6 percent. Occasionally counts have been higher after freezing than before. Counts up to twice the initial count have been attributed to breaking up of clumps of microorganisms during freezing. Also an increase in freezing rate reduces the lethal effect of freezing.

Thus, there are many factors which affect survival following freezing. By summarizing data from a number of sources, we find survival rates over the whole range of 1 to above 100 percent, but averaging around 50 percent (Table 2). Survival is rarely below 1 percent and freezing appears never to sterilize the substrate. Table 2 also shows that survival is greater in the non-acid foods. These counts were made from a few minutes to a day after freezing. The effect of low temperature storage for a short time is therefore superimposed on that of freezing.

Table 2. Percentage of psychrophilic organisms surviving freezing one day or less.

Survival %	Number of reports: Non-acid foods and media	Number of reports: Acid foods
over 100	5	0
60 to 100	17	0
20 to 59	20	1
1 to 19	16	4
less than 1	1	3

Killing is not entirely a storage effect because survival is a greatly reduced by repeated freezing and thawing. That killing is an effect of freezing rather than merely of low temperature is shown by the comparatively slight effect of supercooling to 26.6° F. (97 percent survival) as compared with freezing at this temperature (2 percent survival).

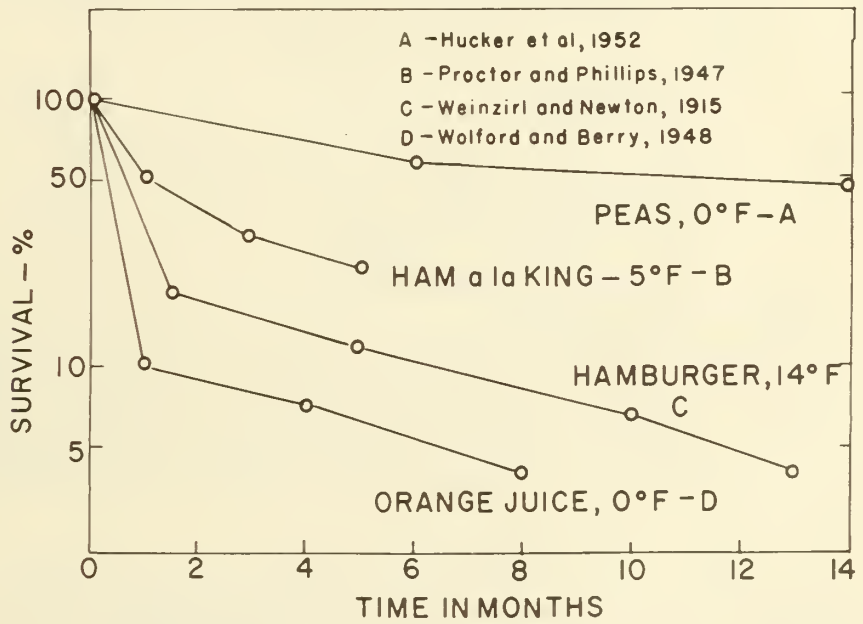


Figure 2. Effect of storage at various temperatures on microbial counts in various foods.

In dealing with frozen foods, we must consider the effect of freezing but what we are really interested in is the effect of prolonged low temperature on the microbial flora. When foods are stored over many months and samples are removed for counts from time to time, one finds survival patterns such as shown in Figure 2. Note that survival is poorest in the orange juice -- an acid product. After the first count following freezing, survival may be logarithmic or nearly so, but survival is not always logarithmic. This would not be expected when we are dealing with a mixed population, because the more sensitive

organisms will die first. Survival curves for the natural inoculum on frozen foods often show little or no decrease in count as storage time increases. Figure 3, for example, shows almost complete survival at the lower temperatures. (Where two temperatures are given there was a daily fluctuation between the two.) Populations exceeding 10,000 per gram have been found on frozen vegetables after 11 years' storage. Foods never become sterile during frozen storage.

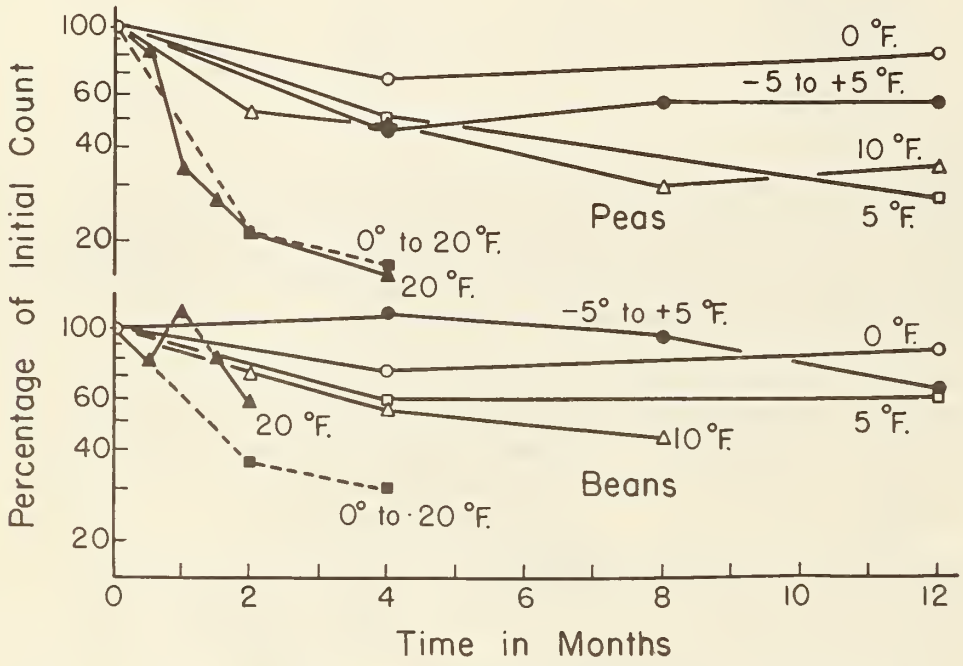


Figure 3. Effect of time and temperature on survival of bacteria.

Figure 3 also shows how survival increases as the temperature is reduced. This is almost always true when survival rates at different temperatures within this range are compared. We should add that the initial counts for these survival curves were made after the product had been frozen. Thus they describe only storage survival and there is no sudden initial drop due to the lethal effect of freezing itself.

That survival is different for different organisms is shown in Figure 4, which compares survival rate of different species of Salmonella. Differences of this magnitude have been observed repeatedly. Note the lack of conformity even between the two curves for Salmonella typhosa. Of course they represent different conditions, and in addition they may be different strains.

When the initial population is large, the proportion which survives is often smaller. Figure 5 shows that the percentage of survival was one-fifth as great in frozen orange juice with an initial count of 31,000,000 per ml. as in a lot whose initial count was only 12,000 per ml. Of course in absolute numbers there were more survivors in the first lot because of its extremely high initial count.

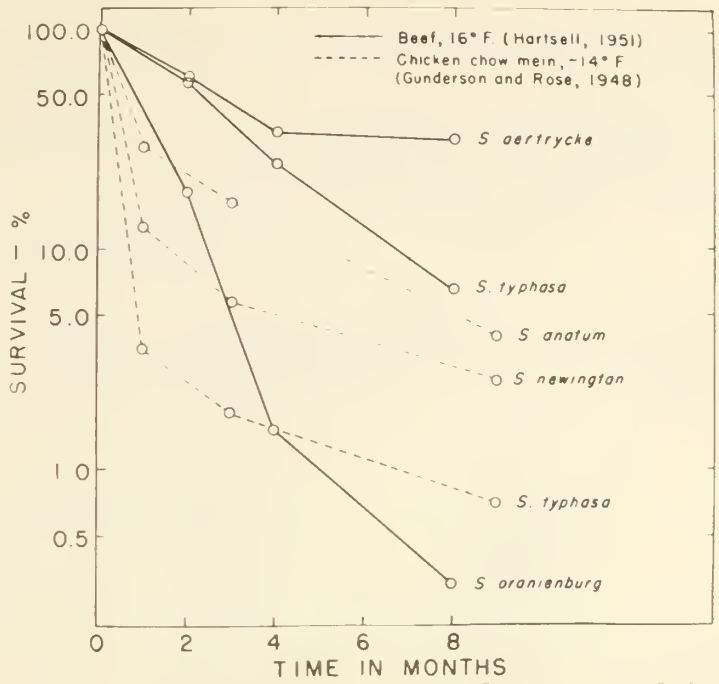


Figure 4. Storage survival = comparison of species of Salmonella.

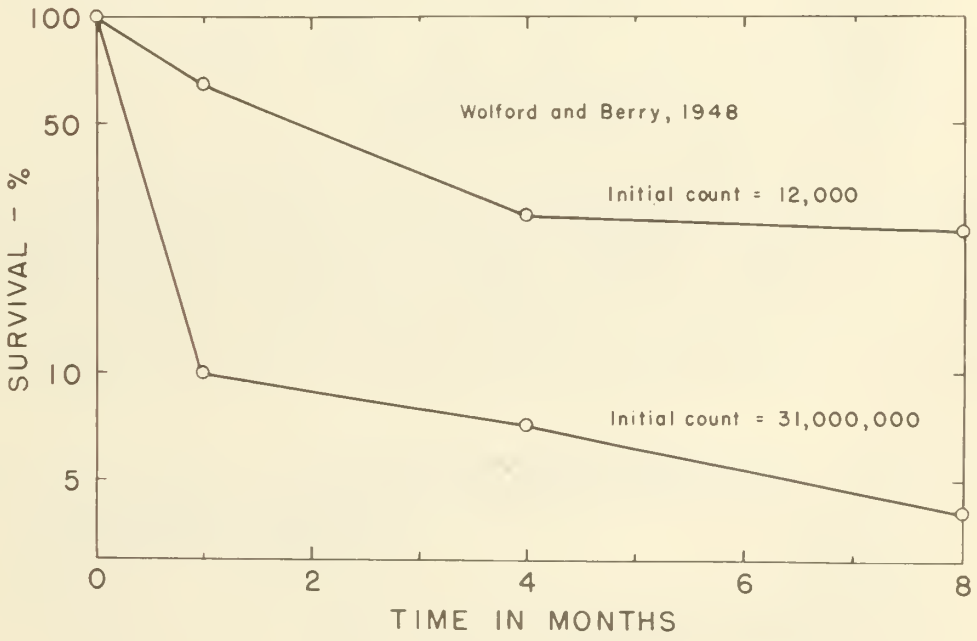


Figure 5. Survival in high- and low-count orange juice held at 0° F.

As with freezing survival, storage survival may be enhanced or reduced by differences in composition of the environment. For example, the addition of sucrose or dextrose to water protected Saccharomyces cerevisiae from the effects of freezing (Figure 6). Similar observations can be made in foods. Under a particular set of conditions, survival of another yeast, Torulopsis in orange juice for 18 months was less than 0.1 percent. The addition of 50 percent sucrose to the orange juice increased the survival to 54 percent.

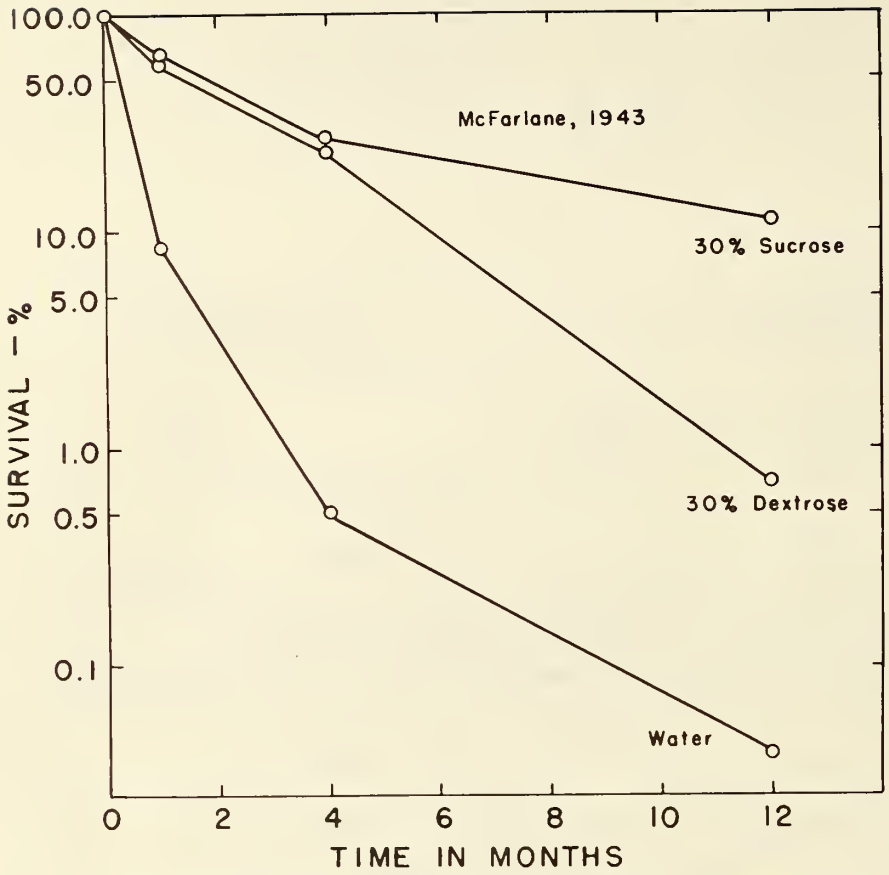


Figure 6. Protective effect of sugar on survival of yeast at 0° F.

A considerable number of published papers give data on survival of microorganisms in foods and microbiological media stored at subfreezing temperatures over periods of many months. Table 3 summarizes a number of these data. Each datum counted in the table was for a particular product and set of conditions, stored for a period that usually approximated four months. This table shows that, as previously stated, greater survival rates are found at lower temperatures.

Table 3. Effect of storage temperature on survival after 3 to 5 months

Survival %	Number of reports	
	Above 0° F.	Below 0° F.
over 50	1	12
20 to 50	6	23
1 to 20	23	15
less than 1	8	1

These data are compiled from many sources, and the great variability in survival rate is due of course to variation in the factors we have discussed, such as composition of the substrate, the temperature, and the kinds of organisms comprising the experimental population.

Sampling variations also frequently cause what appears to be large variations in survival. We have found this true even with a food as homogeneous as peas. For example, we made the counts shown in Table 4 on packages of frozen peas that had been assumed to be identical. Within each of the four lots, all of the product passed through the processing line within a half hour. It was then packed in dry ice, shipped to Western Regional Research Laboratory, and stored at -20° F. until the counts were made. Other products showed greater uniformity, but it was common to find variations of several-fold between the lowest and highest count in a lot.

Table 4. Package variability of bacterial population in peas.

Count per gram in packages stored at -20° F.			
Lot 3	Lot 4	Lot 5	Lot 6
43,000	17,000	34,000	210,000
58,000	39,000	39,000	220,000
78,000	47,000	40,000	250,000
79,000	66,000	44,000	330,000
82,000	68,000	53,000	370,000
99,000	91,000	55,000	480,000
240,000	94,000	58,000	500,000
1,100,000	170,000	65,000	1,100,000
	900,000	67,000	1,200,000
		1,200,000	1,400,000
			1,500,000
			1,500,000
			2,100,000
			2,100,000

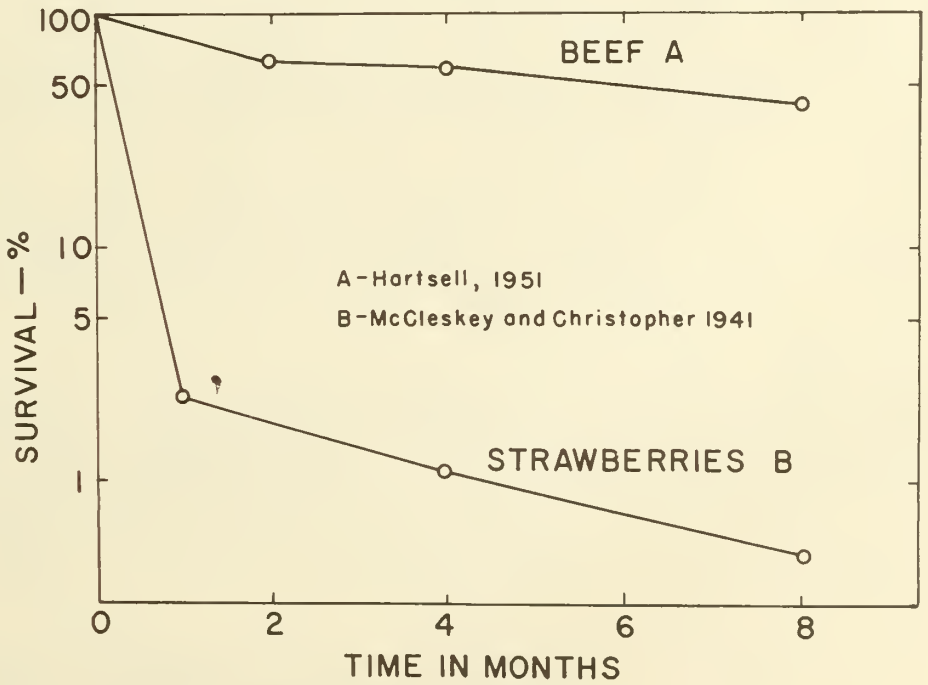


Figure 7. Survival of Staphylococcus aureus at 0° F.

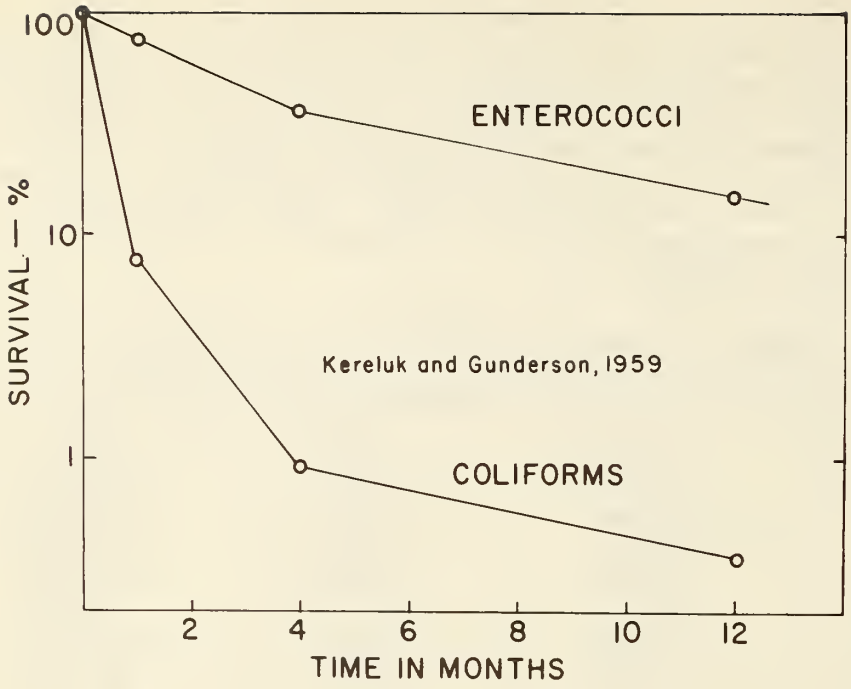


Figure 8. Survival of fecal indicators in chicken gravy at 6° F.

Pathogenic bacteria survive at subfreezing temperatures as do other organisms. It was reported as early as 1887 that typhoid bacilli survived in river and lake ice harvested and stored for summer use. We have shown survival curves for some salmonellae. Staphylococci also persist for many months (Figure 7), although they die more rapidly in the acid than in the nonacid food. Spores of Clostridium botulinum appear to remain almost indefinitely in frozen food in undiminished numbers. As previously shown, food poisoning organisms do not grow in foods at freezer temperatures. If they are in the food when it is frozen, however, it must be assumed that they are likely to remain viable even during prolonged storage.

Fecal indicators also persist at freezer temperatures. Coliforms, although frequently enumerated for the purpose of detecting fecal contamination, do not survive as readily as the enterococci (Figure 8). E. coli, in turn, does not survive as readily as many other coliforms. Later we will discuss this as it affects microbiological standards.

In summarizing the available information on the survival of microorganisms it may be stated that survival varies greatly with the environmental conditions and with the species and strain of organism. In any population, some individuals are killed by freezing; others withstand freezing but die during subsequent low-temperature storage. Survival may vary between extremes of a fraction of a percent and 100 percent, but is commonly in the range of 1 to 50 percent. Survival increases as the temperature is reduced.

In view of the present interest in microbiological standards, these facts have considerable significance. Foods with counts considerably exceeding any

specified limit might fall below this limit if stored for a sufficient period, especially at relatively high temperature.

Minimum temperature for microbial growth and spoilage in foods. To find the minimum temperature at which growth can be expected during low-temperature storage, we have assembled and summarized the published reports of growth at low temperatures. Growth can occur at subfreezing temperatures. Peas at 25° F., for example, appear to be frozen, but they can support bacterial growth and the count can rise during the course of a few weeks to over a billion per gram. Such peas are spoiled bacteriologically just as if they had been thawed and allowed to spoil.

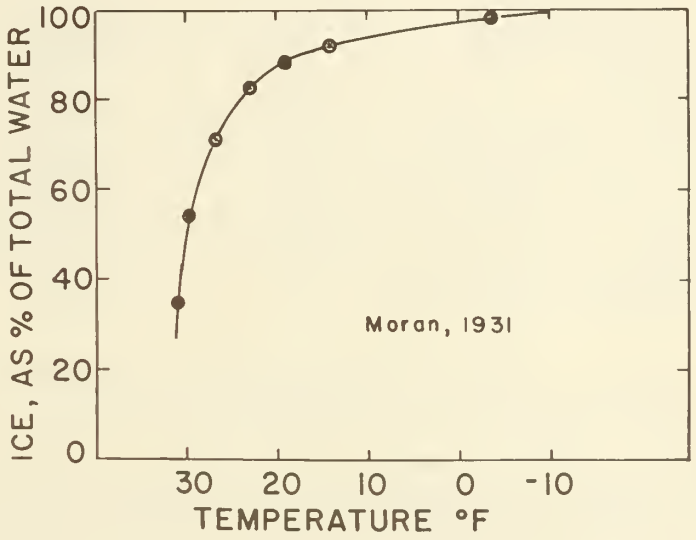


Figure 9. Formation of ice in meat in the course of freezing.

At the outset it seems surprising that microorganisms can grow in frozen food. Although foods appear to be completely frozen when cooled to slightly below 32° F., they actually contain liquid water until very low temperatures are reached. For example, the water in meat was found to be only 82 percent frozen at 23° (Figure 9). Other reports confirm these data and they apply to vegetables and fruits as well as meat. In general, foods are not completely frozen in the temperature range at which they are ordinarily stored.

During the partial freezing which occurs at these temperatures, the solutes (and probably also the microorganisms) become concentrated in the unfrozen portion. Under such circumstances the concentration is dependent on the temperature and increases as the temperature is reduced. Presumably growth occurs in the unfrozen portion of the food, but as the temperature is reduced the solutes become so concentrated that growth is no longer possible.

In order to discuss this subject, we must consider the method by which the minimum temperature for microbial growth has usually been determined. A food or other substrate (either with its natural microflora or one added artificially) is stored at a low temperature, or preferably at a series of low temperatures. It may take weeks or months for growth to begin at these temperatures, and the experimental product must be observed periodically for evidence of growth.

In practice, we are usually dealing with mixed populations in which some strains or species may be dying off while others are starting to grow. In reviewing the literature, we also find that many authors have merely reported that they observed growth at certain temperatures. Many did not give lower temperatures at which they did not observe growth. Duration of exposure and other experimental conditions are usually given but are of course not standardized. In our opinion the best way to summarize these data is to list the various low temperatures at which growth has been observed.

We found about 150 records of growth at subfreezing temperatures, scattered over about 100 reports. It would be difficult to show you all of the data, but as an example, what we found for vegetables at and below 25° F. is shown in Table 5. Note that most of the records are for the upper part of the temperature range -- above 20° F. -- and that it is commonly molds that grow at the lower temperatures. We prepared similar series of data for meat, fish, fruit, and for records of microbial growth on media, soil, etc. We summarized all of this in Table 6. From this you will see that there are many records of microbial growth at temperatures above 20° F., and that growth has been observed a number of times in the range of 20° to 14° F. Although several reviewers have stated that 14° F. is the approximate lower limit of microbial growth, we found a few published reports of growth between 14° F. and 10° F., and a few others at temperatures far below 10° F.

These records are of special interest to us and we have listed them in Table 7. Let us consider first those between 14° and 10° F. Growth is not often observed in this range, but these temperatures are close enough together to corroborate each other. They seem to indicate that occasionally conditions are established (suitable species and strain of organism, suitable substrate, etc.) so that growth occurs in this temperature range. We know this is relatively unusual, because a considerable number of other authors reported absence of any growth at these temperatures, and because at least 12 authors have recommended 16° or 14° F. as the maximum safe storage temperatures for frozen foods. Also we have found no report of a comprehensive series of experiments with published data showing growth in the range of 14° to 10° F.

There are other reports (Table 7) of growth at temperatures far below 10° F. None of these has been confirmed and at least two were made before modern refrigeration became available, so that one wonders if the temperatures reported could have been maintained continuously. Nevertheless, it is possible that special conditions occasionally exist which permit growth at these temperatures. The best evidence that growth does not generally occur in foods in this temperature range is that billions of cartons of frozen food have been stored at or near 0° F. without microbial spoilage.

From these data collected from a considerable number of investigations, we may conclude that microbial growth commonly occurs in frozen foods at temperatures above 20° F., and occasionally down to 14° or possibly 10° F. In view of this information, it would seem that the danger of microbial deterioration in a food stored below 10° F. would be infinitesimal, but that danger of microbial deterioration and spoilage becomes increasingly great as temperature rises above this point.

Table 5. Microbial growth at low temperatures on vegetables.

Product	Class of organism	Temperature °F.	Author
Vegetables	Bacteria	25	Berry, 1934
Peas	Unspecified	25	Diehl et al, 1936
Vegetables	Bacteria	25	Michener et al., 1960
Peas	Bacteria	24.8	Berry, 1933
Peas	Bacteria	24.8	Berry and Magoon, 1934
Vegetables	Mold	24.2	Torok and Alamasi, 1954
Peas	Mold	23	Anon., 1931
Vegetables	Bacteria	20 to 25	Fabian, 1946
Vegetables	Bacteria	20 to 25	Bedford et al., 1945
Vegetables	Mold	20	Berry and Magoon, 1934
Peas	Mold	20	Diehl et al., 1936
Soy beans	Mold	20	Wolford (unpublished)
Peas	Mold	20	Michener et al., 1960
Vegetables	Mold	19.4	Haines, 1937; Anon., 1937
Home gr. foods	Mold	18	Diehl and Warner, 1945
Vegetables	Mold	15	Bedford et al., 1945
Peas	Bacteria	10	Hucker and Robinson, 1950

Table 6. Growth of microorganisms at low temperature.

Temperature °F.	Number of reports		
	Bacteria	Molds	Yeasts
32 to 28.5	21	6	4
28.4 to 24.9	15	8	0
24.8 to 21.3	18	12	3
21.2 to 17.7	9	20	2
17.6 to 14.1	5	7	0
14.0 to 10.6	2	1	1
10.5 to 10.0	2	2	0
below 10.0	2	1	2

Growth at low temperatures. In any discussion of growth of microorganisms, one must consider the typical bacterial growth curve (Figure 10). In general, there are four phases in growth of a population. The lag phase is the initial period when the bacteria are getting used to their environment. There is no reproduction; many may die, so that the total numbers of live cells may even fall. Then, they begin to multiply and their numbers increase logarithmically, giving us the term logarithmic phase. As the food is used up and waste products accumulate, reproduction slows until the increase stops. This is the resting phase. Then the cells begin to die in large numbers, and the colony is in the death phase.

So far as danger to health and decomposition of foods is concerned, we are primarily interested in the lag phase and in the logarithmic phase, that is, in

the time for initiation of growth and in the period of rapid growth. In most instances (and there are a few exceptions) there must be large numbers of food-poisoning organisms to cause illness; and in most cases, decomposition cannot be demonstrated until the numbers of bacteria are very high. Usually a food is putrid before the resting phase is reached, and studies usually stop at that point. Table 8 gives representative data to show bacterial levels at first evidence of odor or slime in several foods. Note that with few exceptions, counts are in the high millions in decomposed material.

Table 7. Microbial growth at temperatures below 14° F.

Organism or group	Substrate	Temperature °F	Author
Bacteria	Fish	12.2	Redfort, 1932
Total count	Fish	12.2	Shewan, 1953
Marine bacteria	Media	12.2	ZoBell, 1942
Molds and bacteria	Media	10.4	Jensen, 1943
Mold	Raspberries	10.0	Beckwith, 1936
Bacteria	Peas	10.0	Hucker and Robinson, 1950
Yeast	Orange juice	0	Shrader and Johnson, 1934
Pink yeast	Oysters	0	McCormack, 1950
Psychrophiles	Ice cream	14 to -4	Beckler and Dusossoit,1908
Bacteria	Media	-4	Richardson & Sherubel,1909
Pink yeast	Media	-22	McCormack, 1950

Table 8. Bacterial level at odor or slime point (in millions per gram or per square centimeter).

Food	Odor	Slime	Author
Poultry meat	10	30	Walker & Ayres, 1956
Beef	10	100	Kraft & Ayres, 1952
Frankfurters	10 to 30	30	Kraft & Ayres, 1952
Fish	10 to 300		Schwartz & Zeiser, 1939
Oysters	0.01 to 0.5		Boyd & Tarr, 1956
Crabmeat	100		Alford et al., 1942
Shell eggs	10		Miller, 1954
Frozen eggs	5		Lepper et al., 1944 & 1956
Chicken pies	0.1 (flavor)		Peterson & Gunderson,1960

We have already pointed out that the food-poisoning bacteria cannot grow and cannot produce toxins at temperatures lower than 40° F. When we speak of growth below 40° F., then, we are speaking of psychrophiles -- defined as microorganisms capable of relatively rapid growth at 32° F. As we have said, some of the psychrophiles are capable of growth below 32° as well, even down to as low as about 14° F. Indeed, it has been demonstrated many times that microbial growth can occur to the point of spoilage at subfreezing temperatures.

Growth is exceedingly slow at the lower temperature limits; even when a food actually thaws, there will be no growth for a considerable period. That

is, there is a long lag period before growth commences (Figure 11). This graph shows that when chicken pies are thawed, it takes 10 hours before growth commences at 90° F., but 70 hours at 34° F. We are not implying that thawing and refreezing is a good practice in commerce because such treatment causes physical and chemical deterioration; but certainly if the thawing is only momentary, no bacterial growth can occur. Note, too, in this graph, that a few degrees of change in temperature at the higher range makes little difference in the lag period, but an equal temperature difference in the low range makes an immense difference in the time for initiation of growth. Figure 12 shows that this principle is even more pronounced as we approach the minimum growth temperature. Here, hours become days. Here too, note the small effect of temperature differences on lag at high-temperature ranges, and the large effect at low ranges. Figure 13 shows two turkey pies, both of which were held at 20° F. -- the one on the left for 6 months, that on the right for 9 months. The 6-month pie shows no mold, indicating a long lag period, but large colonies have appeared at 9 months. Exceedingly long lag periods have been shown by others. For example, Gibbons (1934) found a lag period of 50 weeks before bacterial growth occurred on fish at 23° F. Russian workers have found very long lag periods

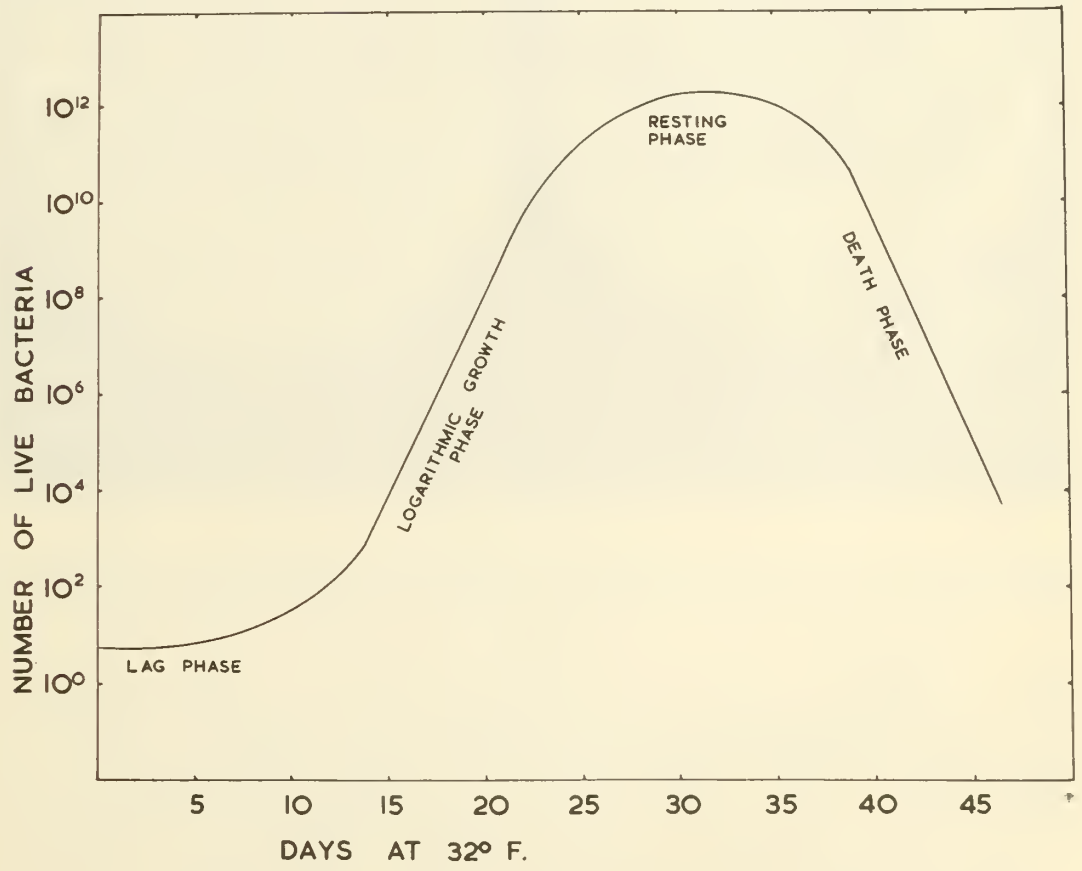


Figure 10. Typical bacterial growth curve

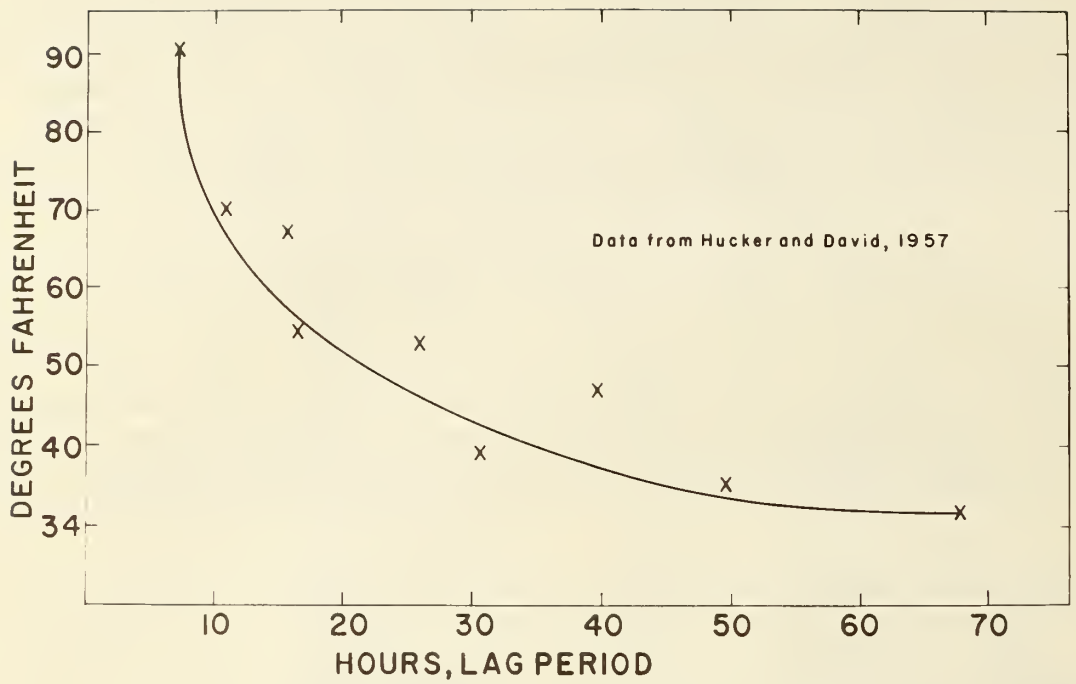


Figure 11. Effect of temperature on lag period of flora in thawing chicken pies.

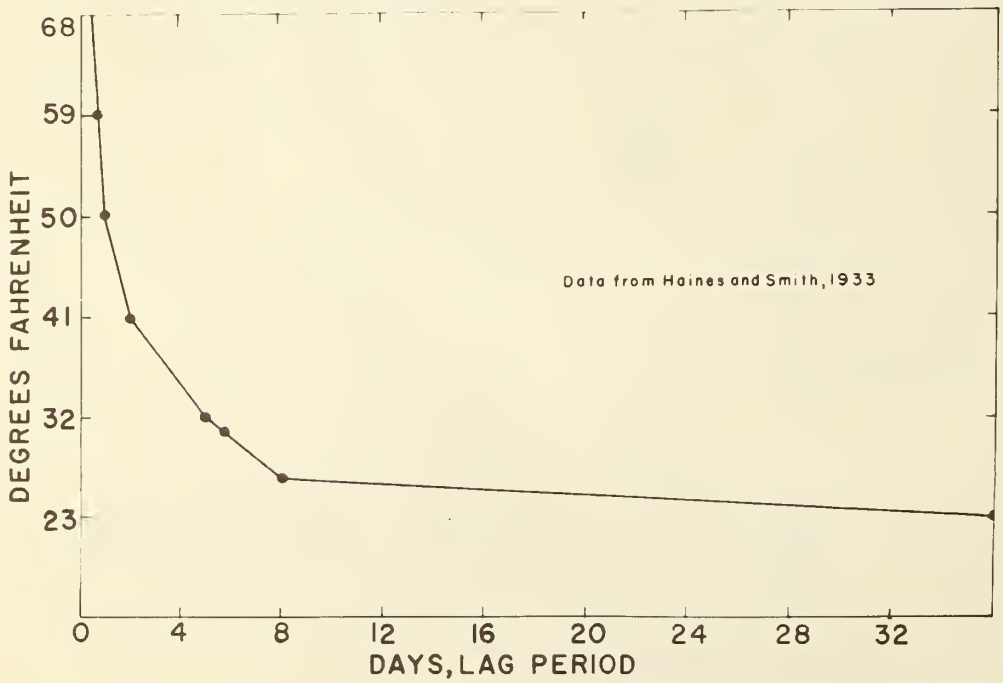


Figure 12. Effect of temperature on lag period of Mucor mucedo.

for some molds. For example, Penicillium glaucum had a lag period of 143 days at 23° F.; an unidentified mold species, 124 days at 17.6° F.; and two strains of Oospora, 54 and 414 days, respectively, at 17.6° F. It is possible that other investigators would have recorded similarly long lag periods with other organisms, had they continued observations for prolonged periods.

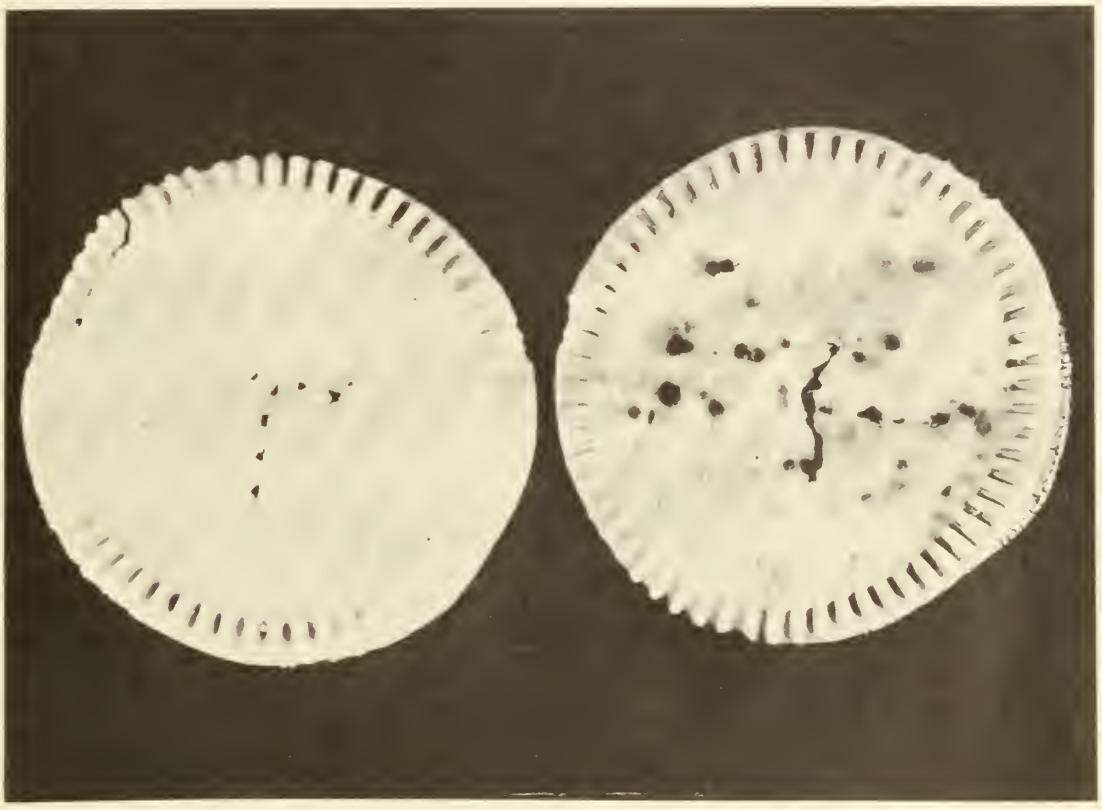


Figure 13. Turkey pies held at 20° F. -- the one on the left for 6 months, that on the right for 9 months.

When an investigator is studying growth at these very low temperatures he must be patient. Too many investigations are terminated before the organisms have had a chance to grow. Of course, if it takes a year for bacteria to come out of lag at a certain temperature, and if a food is held less than a year at that temperature, for all practical purposes, no bacterial growth will occur in this product in commerce. These illustrations demonstrate the length of time it takes for growth to start, that is, the length of the lag phase.

Growth at low temperatures.

After the bacterial colony has entered the logarithmic growth phase, temperature has a similar effect on the rate of reproduction, that is, on the slope of the logarithmic portion of the growth curve (Figure 14). We include this figure for chilled chickens and others that follow merely to demonstrate some principles. Note that when chickens are held at 32° there is a long lag period, whereas at 40° and 50°F. there is a progressively shorter lag. Also, the slope of the logarithmic phase is much steeper at the higher temperature. Also, note, and this is very important, that the effect of the 8-degree difference between 32° and 40° is much more marked than the 10-degree difference between 40° and 50°F. If we were to plot the keeping time, that is, the time it takes to reach the odor point (about 100 million bacteria per square centimeter) against temperature, we would have this same thing presented in a different way (Figure 15). These same data are combined with those of other workers. Note that a few degrees of difference at a higher temperature make little difference in keeping time, but the same temperature differential at the lower range makes an immense difference in the time it takes for the bacterial growth to occur.

As with the lag period, this effect becomes much more pronounced as we go below freezing and approach the minimum growth temperature for psychrophiles (Table 9). This table shows the effect of temperature on the growth of Pseudomonas. Note especially the generation time; that is, the time required for one cell to become two. It is extremely long at 27° F. (56.8 hours). The tendency for small changes in temperature to have a more pronounced effect in a low range than in a high range can be put in another way: the temperature coefficient of growth is much higher at low temperatures than it is at high temperatures.

Table 9. Effect of temperature on growth of Pseudomonas fluorescens in nutrient broth (from Hess, 1934).

	Temperature, °F.			
	68°	41°	32°	27°
Lag phase (days)	1	3	4	6
Generation time (hours)	1.5	6.7	30	56.8
Days to reach maximum count	3	29	46	60

And now let us touch on enzyme production and the effect of temperature on enzymes of bacterial origin. Bacteria produce more enzymes at temperatures somewhat below the optimum for growth than at the optimum. For this reason, enzyme production by bacteria in foods at chill or high freezer temperatures is high. Of course, enzyme activity is also dependent on temperature, being lessened as temperature is lowered. Because enzyme activity is chemical in

nature, the temperature coefficient does not differ as much from the lower temperature ranges to the higher ones, and thus bacterial enzymes are believed to be active at temperatures below the range where bacterial growth can occur. Very little work has been done in this field. One report showed that high

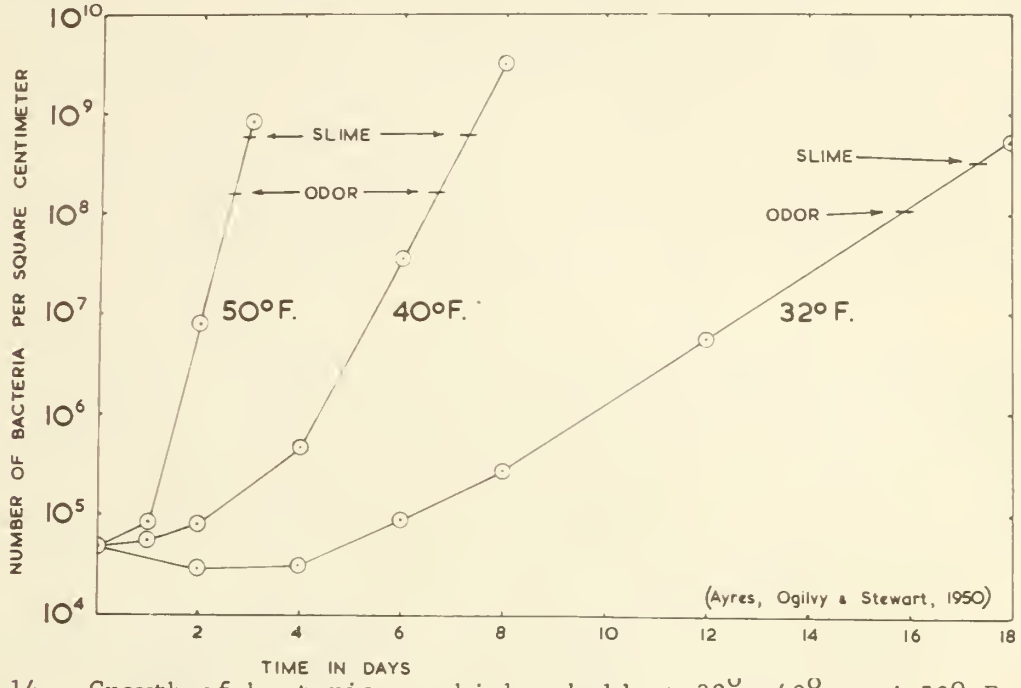


Figure 14. Growth of bacteria on chicken held at 32°, 40°, and 50° F.

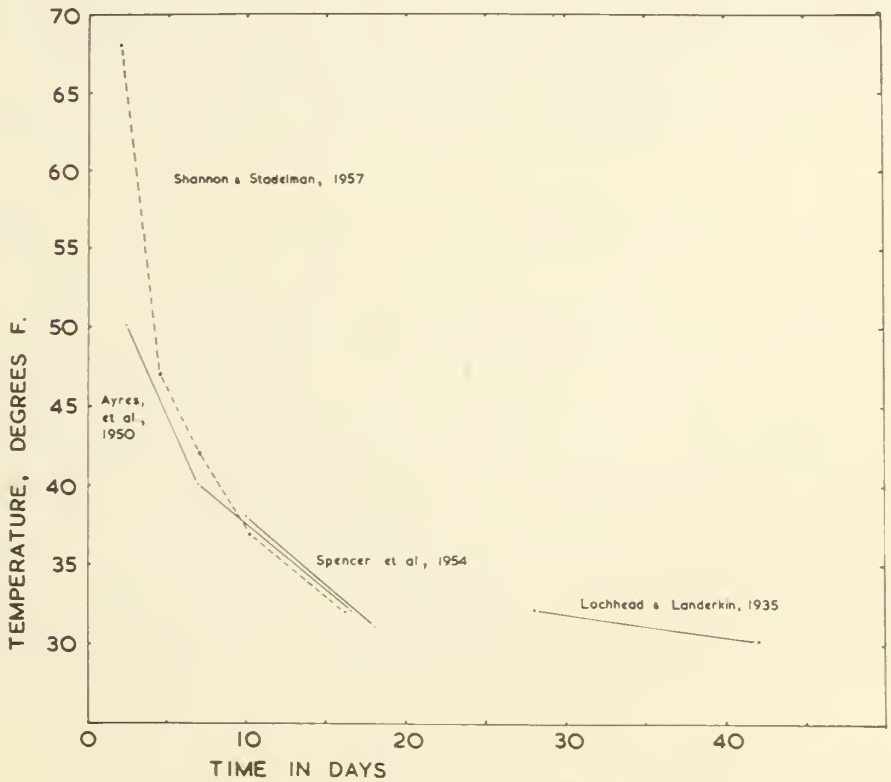


Figure 15. Effect of temperature on shelf life of chilled poultry.

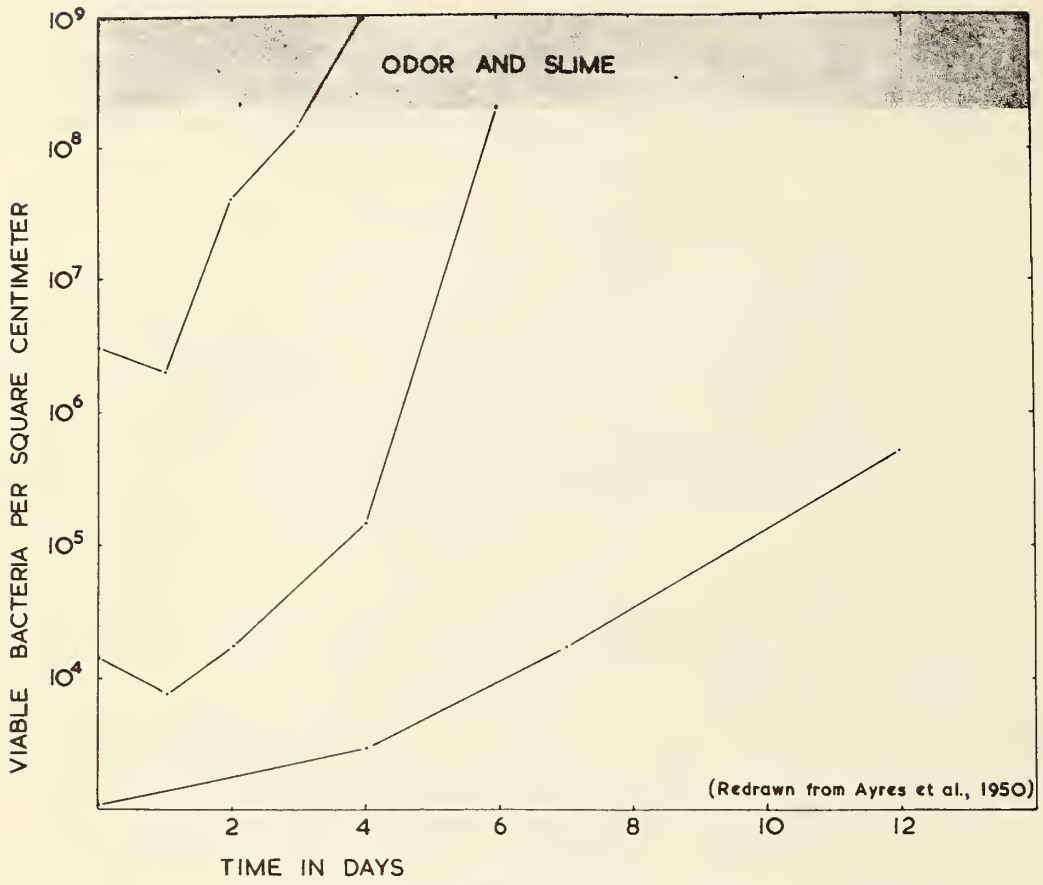


Figure 16. Effect of initial contamination on storage life of chicken at 40° F.

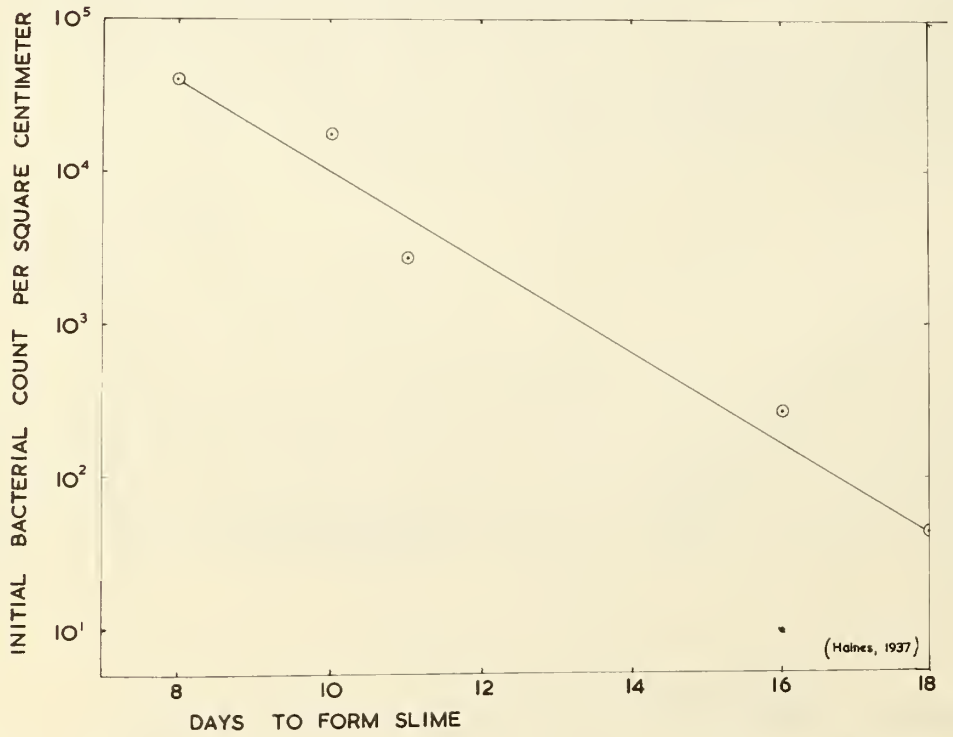


Figure 17. Effect of initial contamination on storage life of beef at 32° F.

bacterial level had a deleterious effect on quality of frozen pork, causing off-flavors and rancidity. Perhaps more work should be done to determine the effect of insanitation or delayed freezing on subsequent shelf life at proper temperatures for frozen storage.

Before bacteria, yeasts, or molds can grow in a food, of course, not only must the temperature be suitable but other conditions as well. For example, bacterial psychrophiles do not grow readily in fruits because the pH is too low; molds and yeasts, however, do well. The neutral foods offer appropriate substrata for bacteria as well as molds and yeasts. Any antiseptic or antibiotic used to prevent or slow growth at chill temperatures will be effective against microbial growth at high freezer temperatures too; often their effect is much more pronounced as temperature is lowered. However, because a low freezer temperature is a more logical means of controlling microbial growth, there has been little attention to this possibility.

If foods are held at temperatures suitable for growth, length of the lag period and rate of growth are also influenced by the numbers of organisms initially present. Again, because there have been no similar studies for frozen food, we will have to borrow from the literature on chilled foods (Figure 16). This graph shows that when chickens are initially contaminated with large numbers of bacteria, the lag period is short and growth rapid. If small numbers are initally present, the lag period is long and rate of growth slow. If we were to plot the time it takes for spoilage to occur against numbers of bacteria, we would have a graph showing the same thing in a slightly different way. Figure 17 shows the relationship between initial contamination and the storage life of beef. If contamination is initially high, the meat will keep only 8 days; if it is low, it will keep 18 days. This principle would likewise apply to foods held at high freezer temperatures, and is an argument for good sanitation in the processing plant. If a product from an insanitary operation is mistreated by being held at too high a temperature, or is held thawed by the housewife too long, it will lose quality much more quickly than will a product that comes from a clean plant.

Summary. And now we should like to summarize the principal points we have made thus far.

(a) Freezing reduces the microbial population of foods, but considerable numbers usually survive even prolonged frozen storage. Reduction of storage temperature increases survival. (b) Food-poisoning bacteria have not been reported to grow below 40° F., but they survive freezing. (c) Some fecal indicators can grow at 32° F. but E. coli cannot. Enterococci survive freezing better than the coliform group, which in turn survives better than E. coli. (d) The minimum temperature for growth of psychrophiles is probably between 10° and 14° F. (e) Growth slightly above this minimum takes many months to become evident. Growth may be greatly accelerated by a slight increase in temperature. (f) Foods with a high count spoil faster than those with a low count, when held at a suitable temperature for growth. (g) There is a possibility that high counts adversely affect quality even at storage temperatures below the growth range.

Standards. This afternoon, as you know, we will have a round-table discussion on microbiological standards. We think it would be of interest, to summarize some of the discussions we have seen in the literature. A more complete study has been prepared as part of our review and will be published. We wish to make it clear that we are not taking a stand for or against standards, but are merely citing arguments and precautions we have encountered. Many of these points will be evaluated in the panel discussion this afternoon. Most authors who have reviewed the question of bacteriological standards have given arguments both for and against, and have concluded that they should be applied with caution. Such standards have the advantage of putting questions of safety on a convenient numerical basis. Furthermore, Canadian workers have reported that promulgation of standards has invariably raised the hygienic level of the products controlled.

First, let us consider the relationship between bacteriological standards and safety. Everyone recognizes that pathogenic food-poisoning bacteria are a potential danger in any food. But many have argued that the history of food-poisoning outbreaks from frozen foods is excellent and that there is no need for standards; on the other hand, proponents of standards have pointed to the incomplete investigation and reporting of outbreaks, and have argued that there may be more outbreaks than we realize. They have pointed to laboratory studies that have shown grossly mishandled precooked frozen foods to be truly dangerous. Some have proposed that pathogens should be absent from foods; but others have questioned that a microbiological standard can accomplish this end. Some pathogens, such as Salmonella or Staphylococcus, have been shown to be so ubiquitous that their presence in some commercial foods is unavoidable. Also sampling and analytical methods have been described as inadequate to guarantee that pathogens present will be detected. Some have argued that control at the source is a better way -- through inspections of the plant operation, by enforcement of handling codes, or by processing procedures such as pasteurization, which would be more certain to result in a pathogen-free food.

A most important part of any of the proposed standards is a "total count" of viable aerobic bacteria. English workers have found that foods causing poisoning outbreaks usually had total viable counts above 10 million per gram. On the other hand, these same workers found Salmonella on meats with very low total viable count. The assumption by many that low total count indicates safety has been shown to be sometimes but not always true. Furthermore, high counts of non-pathogenic organisms, such as psychrophilic saprophytes, would have no public health significance.

The relation between bacterial levels and quality is open to less controversy. Some authorities have pointed to standards as being a measure of sanitation, adequacy of refrigeration, or speed of handling. Others have indicated that to distinguish which of these factors caused a high count would be impossible with only a total count on the product as a guide. Some investigators have said a high count affects flavor adversely before actual spoilage is evident, and this may be a factor in competition on today's market. It is well established that initial bacterial level affects the shelf life of a chilled product. Methods of analysis are more nearly adequate for counts than for pathogens, but they need improvement, and should be clearly specified as part of any bacteriological standard. Foods with high count could sometimes be

brought into compliance merely by storing them for a sufficient period frozen, or by heating them slightly. This has been cited by some authors as being a distinct disadvantage of bacteriological standards.

The coliform group and enterococci have been shown to be ubiquitous and therefore should not be used alone to indicate fecal contamination, and although Escherichia coli has greater significance, its source should be determined each time it is found.

Various reviewers have expressed the need for caution in the application of standards. The principal precautionary arguments we have found are as follows:

(1) A single set of microbiological standards should not be applied to foods as a miscellaneous group, such as "frozen foods" or "precooked foods."

(2) Microbiological standards should be applied first to the more hazardous types of foods on an individual basis, after sufficient data are accumulated on expected bacterial levels, with consideration of variations in composition, processing procedures, and time of frozen storage.

(3) When standards are chosen, there should be a definite relation between the standard and the hazard against which it is meant to protect the public.

(4) Methods of sampling and analysis should be carefully studied for reliability and reproducibility among laboratories, and chosen methods should be specified in detail as part of the standard.

(5) Tolerances should be included in the standard to account for inaccuracies of sampling and analysis.

(6) At first, the standard should be applied on a tentative basis to allow for voluntary compliance before becoming a strictly enforced regulation.

(7) Microbiological standards will be expensive to enforce.

(8) If they are unwisely chosen they will not stand in court of law.

INDUSTRY PROBLEMS IN HANDLING FROZEN FOODS -- PANEL DISCUSSION

Cliff D. Carpenter
Consultant, Laguna Beach, California
Moderator of Panel

It is apparent to all in the food industry that there are problems in handling frozen foods. It is equally obvious from examining the list of participants on this panel, that there are at least five problem areas. It is timely, therefore, to bring together qualified representatives from these five areas to discuss these problems - since all of us need to be aware of the other fellow's problems, and since failure on the part of one may create problems for those in other areas.

For example: since the frozen process is basically applied by the packer or processor, he is at the head of the line. And if he fails to process the product properly, or to protect it properly by underpackaging, his failure may create problems for the trucker, the warehouseman, the distributor, and the retailer.

A mythical circumstance will serve to illustrate what could happen to four of these five services -- because of the failure of one. A turkey processor is packing two 28-pound frozen young toms to the case, using a light paperboard. The turkeys left the plant in fine shape, but the loading, the 350-mile ride to the refrigerated warehouse, the unloading, and the stacking in the warehouse result in stress on each case. The paperboard is neither as strong nor as sturdy as when the turkeys began this trip.

Let's examine what could happen. Suppose these turkeys will be stored four to five months, then sold to a distributor 700 miles away.

First, the warehouseman wasn't able to stack these turkeys normal height -- or if he had, knowing that they would be in storage several months -- some of them would not have stayed stacked during this time. Package fatigue set in, the bottom two or three cases wilted from a combination of moisture and stress, and expensive rehandling resulted.

But our mythical trouble has only nicely started. The trucker can't build a good load with such "tired" cases. Then, when they are received by the distributor, he may not be able to deliver them immediately to the retail outlets, and so they are again stored. By now, our stacking problem is really severe and package failure has resulted. And by the time they are delivered to the retailer, there could be actual spillage.

The result is that every one of the three services involved has had extra expense in handling this load. Without belaboring the point, 10 cents a case more for the original package would have prevented the problems all along the service line and avoided the accompanying losses.

In a packaging conference held in Chicago about eight months ago by The Refrigeration Research Foundation, Package Research Laboratory introduced a wirebound wrap-around for fiberboard cases, which permits total stackability

and prevents package fatigue. I have seen instances of tired turkey boxes which could have been totally prevented by using such protection.

Many of industry's problems do not yield to such a simple solution. At an early date -- in fact, in 1948 -- industry recognized the interrelation and interdependency of these five services. Thus, comprehensive research was recommended and initiated, and today we are beginning to get some needed answers. Conferences like this one are one notable result.

Industry is profoundly impressed with the work load that has been processed through this Regional Laboratory. It has been estimated that since the TTT program was launched, about 75,000 samples of product have been used to reach the conclusions cited by these researchers at this meeting. The amount of work required to accomplish these results can be equalled only by the term used to describe California olives: Super Colossal!

I feel we can agree that it takes time for industry to catch up to research. Comprehension must be followed by appreciation, before activation becomes a realization.

The processor is charged with the responsibility of properly packaging quality frozen foods. The retailer is our representative to the consumer. All she knows is what the package tells her at the counter, and later, how good its contents are at the dining room table. She knows practically nothing about all the services and all the care required to maintain a high-quality product before it reaches her. But these same services are the guarantee that she will get quality frozen foods.

This integration of effort, as expressed by this overall industry committee, lends encouragement to all concerned that, given the essential time, desired objectives can and doubtless will be reached. Here, as in the case of TTT research, time is an important ingredient.

We therefore approach today's panel discussion of some of industry's problems, and the steps being taken to solve them, in time order -- following the flow of commodity from processor to retailer.

TRUCKING INDUSTRY PROBLEMS IN FROZEN FOOD HANDLING

Milton D. Ratner
Emery Transportation Company, Chicago

It is a pleasure to appear here in behalf of the trucking industry and in concert with men who represent other industrial groups interested in improving the handling of frozen foods. It is particularly a pleasure to return here to this laboratory where a number of years ago I had my first exposure to the results of the comprehensive time-temperature tolerance experiments conducted on frozen foods.

My assignment here today is to discuss the trucking industry's problems in handling frozen foods. At the outset, I would like to answer those who regard my industry as one of the weak links in the chain of frozen food handling. This laboratory has demonstrated clearly that the distribution chain is directly affected by both time and temperature -- and where the trucking industry may have some overall weakness in temperature, it has offsetting strength in conservation of time. The speed and the flexibility of the modern motor truck is, I know, familiar to all of you. Frozen foods are in transit from one day to seven days for an average of three days in an over-the-road trucking movement; and in distributive trucking a delivery takes from one hour to two days with an average of five hours. This is really a short period of time in the life of any frozen food. But, our industry does have its problems in handling frozen foods. What are these problems? And, what are we doing to correct them?

We appear at the outset to have a monumental problem with our motor truck and trailer equipment. There are over 100,000 refrigerated trucks in this country and only 35 to 40 per cent are capable of holding zero. Yet close to 75 per cent of the trailers and trucks will do a satisfactory job if used by competent personnel. This seems contradictory, but we know from experience that an ordinary piece of equipment with the lading properly stowed will do a better job than the finest piece of equipment that has been poorly loaded.

Space and weight limitations and lack of uniformity in State laws are problems for our industry. Slowly, but surely, we have been able to remove restrictive laws and now are able to operate heavier and larger trailers. Why is this important in the handling of frozen foods? Primarily because a properly refrigerated heavily insulated trailer weighs from 3500 to 5000 pounds more than a van trailer. This is the extra weight needed to do a good temperature job, and even today the reason why the best equipment cannot refrigerate to a greater extent is due to weight and space limitations of the refrigerating unit.

We are successfully overcoming the lack of knowledge previously so widespread in our industry for setting specifications for new equipment. It will require an investment of approximately $3/4 billion to replace all the equipment not capable of holding zero. Our industry needs the time to accomplish this conversion and, most important, we must assure ourselves that the new equipment we acquire can do the job we expect. The work of the organized

trucking industry and the results of the truck-trailer-industry-sponsored experiment conducted by the United States Bureau of Standards has made it possible to purchase equipment with assurance that the specifications are proper. Fewer trailers are being built today that are not in thermal balance between the heat gain of the body and the capacity of the refrigerating unit. Fewer trailers are constructed today without side wall corrugations or stripping and without overhead ducts for better distribution of air. These two features are essential elements in a first rate piece of equipment. More and more trailers are being constructed today with closed-cellular insulating materials, such as polystyrenes and urethane foam insulations. The closed cells prevent the absorption of moisture and help maintain the effectiveness of the insulating materials over a long period of time. With these materials we can reduce the thickness of the insulation being used when compared with the older types. We are improving and will continue to improve our equipment, but now we would like to focus our attention on another vital element in our business where we have problems.

Our industry has a considerable personnel problem, both at the truck driver and at the supervisory level. We need a great deal more education for our personnel to teach them proper practices in frozen food handling. One complicating factor is the number of people involved. There are tens of thousands of truck drivers in the various companies and, additionally, these drivers frequently handle other types of cargo in their work as well as frozen foods. I think you can see the magnitude of our problem when compared to educating relatively few personnel in a fixed installation, such as a processing plant or a warehouse.

The American Trucking Association is in the process of producing a 15-minute colored motion picture film for the education of drivers and supervisory personnel. The script for this film has been written and the film will be in production later this year -- and available early in 1961. In addition, the ATA Committee on the Transportation of Perishables is producing a comprehensive drivers' manual with instructions for handling frozen foods, which will be available in the near future.

Our drivers must know how to properly operate their mechanical refrigerating units. Our drivers must know how to properly stow lading to provide for free circulation of air, the objective being to float the load in a bath of circulating refrigerated air.

We are urging that we again start stowing loads with alternate cases away from the side walls for better circulation. Our drivers must know how to protect the load under their care, while in transit, and how to handle all emergency situations. These points will all be covered by our new training devices, the film and the manual. Finally, our industry has problems in handling frozen foods that are external to our own companies and to our own equipment and personnel. These problems come about when our units are being loaded and unloaded. Every effort should be made to load and unload frozen foods expeditiously. Every effort should be made to tender product to the carrier at the right temperature. Leaving pallets of frozen foods in the sun on the loading platform during the lunch hour is a prime example of abuse from the Chamber of Perishable Horrors. There are many other abuses that must be overcome.

It has been suggested, and I concur in this, that the warehouse operator become the point of control for the shipper in order to be assured of obtaining proper motor truck equipment from the carriers, and that the warehouse be the control for proper loading practices; that the warehouse require that trailers be precooled to 20°F. This, incidentally, is excellent presumptive evidence that the mechanical unit is in good working condition. I hope warehouse operators will not load equipment that cannot provide for a free flow of air around the lading with side wall stripping and rear door stripping, and equipment that does not have aluminum grooved floors of 3/4-inch depth, or floor racks -- or both.

Our industry is working diligently to improve its equipment and operating techniques and is lending full support to the voluntary program of the Frozen Food All-Industry Coordinating Committee. There has been considerable improvement in the recent past in handling practices and by continued effort in each industrial group and by working together we will find a solution to many, if not all, of our problems.

MARINE TRANSPORT OF FROZEN FOODS

L. L. Westling
Marine Refrigeration Specialist, Oakland, Calif.

Although I am representing The Pacific American Steamship Association at this All-Industry Conference of Frozen Foods, my comments will unavoidably reflect my rather extended personal experience in the field of marine refrigerated transport. My position is not unlike that of the panel spokesmen for the other associated industries.

I am a perfectionist in the marine applications of refrigeration: a perfectionist in matters of physical facilities, of operations, and of stowage - stowage because incorrect stowage can nullify the other two aspects of perfection. The ways of the perfectionist are hard and not always an effective means of improving one's popularity in his own fraternity. Yet I get satisfaction in the belief that I am stimulating a desire for progressive betterments. However, I have always admitted that perfection must sometimes be compromised with inevitable practical limitations of application.

By the same token the formulation of regulatory codes such as those projected by the Association of Food and Drug Officials of the United States (AFDOUS) must allow for these same economic and operational limitations if the code is to have the sympathetic respect of the industries being regulated.

The marine carrier is just as anxious to provide conditions that will promote expansion of the market for frozen foods as any other member of the industrial family that produces or distributes these products. Therefore, over and above the considerations of practical limitations in marine carriage it becomes primarily a matter of timing for compliance with codes and a matter of reasonable economic return for providing these conditions.

The projected code has classified the ship as a "vehicle" and requires that frozen foods be carried at product temperatures of 0° F. or below. Let us see what that does to our American cargo-carrying fleet.

In our wartime shipbuilding program there were built 54 all-refrigerated ships, their primary purpose being to make them available for supplying our overseas military and naval forces with perishable stores. They were all designed for plus 10° F. carriage. Today many of them are carrying logistic supplies and many are in commercial service, and they still have eight or ten years of remaining useful life. Unlike Mr. Burrill's warehouse replacements at $1.00 per cubic foot, we are talking about replacement costs more in the order of $25.00 per cubic foot. On the other hand, the ages of the vessels are such that modernization by re-insulating and adding additional capacity of refrigerating machinery is not economically justifiable. Generally speaking, the great number of vessels built in the 1940's and outfitted for carrying refrigerated cargo were designed to carry frozen foods at plus 10° F. If the code were to be early and strictly applied, should we scrap the all-refrigerated ships, idle the refrigerated compartments of the combination vessels, and surrender this business to the foreign carriers? We are already

alarmed at having lost over half our share of the Oriental freight carriage during the last three years to the resurgent Japanese cargo fleet.

Most of the vessels built in the 1950's and the many now building were designed for zero degrees air temperature. This, too, would be marginal if the code requires that the product temperature be at zero when delivered to the door of the receiving cold storage warehouse or retail outlet. There are less than a dozen ships capable of delivering products at temperatures substantially below zero.

Typical operations of vessels carrying package (break-bulk) refrigerated cargo are thus: The cargo, originating in many sources and at varying distances, is delivered to the marine terminal in trucks and railcars. Seldom does it arrive at temperatures approaching zero. The orderly sequence of receipt defies the efforts of the most dedicated coordinator and cargo stowage planner. The cargo must be loaded in such a manner that it will permit proper sequence of discharge at ports-of-call as, unlike the warehouse, the compartment is loaded chock-a-block. The consolidating operation usually means an interval on the pier without benefit of refrigeration or insulation. In addition, as you are all aware, we have some acute human engineering problems on the waterfront that do not make for dispatch in handling. It should be kept in mind that overseas shipments of frozen foods are almost totally intended for immediate to early consumption and that impairment of "high-quality" life and extended storage life through momentary exposures is not an important consideration.

These human engineering problems to which I refer are forcing the application of containerization methods upon the industry insofar as they can be made acceptable to the various services and facilities. The operation with refrigerated containers is in the midst of a very disturbed development and has its problems. The principal problems have been inherited from the borrowed technique of the highway services, but given time these problems will be solved. On the other hand, there are many services and ship types that will demand the retention of the built-in refrigerator and package cargo handling. A code must not write these necessary services out of business.

A complaint is here registered in the code requirement for pre-cooling of containers that are to carry pre-frozen foods. Unlike the warehouse room that has great heat capacities in heavy concrete floor slab, structural steel and extensive refrigerating apparatus, the marine container has very low heat capacity in the light-weight linings, aluminum floor coverings, and refrigerating apparatus. The heat capacity of the captive air of a container is nil. The code requirement that the interior be precooled to an air temperature of 20° F. can be attained in a fleeting moment by circulating low temperature air from the air cooler without reducing the temperature of the insulation, linings or apparatus to a significant degree. During the interval of loading of the equivalent truck, as has been described at this meeting, thermal equilibrium with the ambient air will take place. Precooling then, as such, is ineffectual and cannot justify the time or effort in the performance and should be left optional with the operator.

The position that I have taken in this regard has exacted from the projectors that the true and hidden meaning of the pre-cooling regulation is that its purpose is to demonstrate the operability of the attached refrigerating machine. The code presupposes that there must be machinery someplace in the picture. But what if there are means, existent or under development, by which adequate refrigeration can be had without attached machinery?

While it is a marine safety measure that prohibits the carriage of carbon dioxide into the compartments of ships, there are other sources of refrigeration for containers that require no mechanical refrigeration. First, the regulation as written would outlaw the loading of sub-cooled produce into an unpre-cooled container. Secondly, there is a method under development in which metered quantities of liquid nitrogen, whose boiling point is minus 320° F., is released into a container loaded with frozen foods. The temperature of the cargo is lowered to a precalculated reading to provide reserve self-refrigeration until destination is reached. The code requirement would be superfluous in this instance.

There is a third projected method in which the frozen cargo may be loaded into a container having highly efficient insulation and without an attached source of mechanical refrigeration. There may be conditions in which frozen foods intended for medium to short haul transport, or out of a refrigerated marine terminal, may be loaded into a sealed container and destined to be stowed in a refrigerated warehouse, break-up room, or in a refrigerated ship's compartment. I have in mind an operation in which a loaded container having four inches of closed-cell urethane foam insulation having an equivalent value of eight inches of corkboard, may be carried for eight hours through a continuous weather ambient of 100° F. with a calculated temperature rise of less than 5° F. This method of operation places the container in an insulated room or hold which would be refrigerated by a remote central refrigeration plant. The container's only mechanical apparatus consists of an internally mounted fractional horsepower exhaust fan which moves the refrigerated air of the compartment through the lading. The inlet air passes through closable low-positioned ports at the door end and passes diagonally and upward through the lading and is discharged through the closable outlet port of the fan.

These variously cited methods are improvements over other existing methods. Care should be exercised in writing codes that they will not stifle such developments.

Participation in All-Industry Conferences such as these results in proper enlightenment on the technological needs of frozen foods and on the several problems of the industries in meeting these needs. They invite cooperation. The shipping industry appreciates the invitation to participate even though the invitation came too late for thorough preparation. It can be anticipated that the shipping industry, like the other associated industries, will plead for an opportunity to voluntarily meet the needs of frozen foods rather than to be subject to restrictive codes having the force of law. It will plead that, if codes are unfortunately imposed, the regulations will be realistic and so timed that through the retirement of depreciated equipment new construction will ultimately provide technologically adequate facilities for the marine carriage of frozen foods.

MICROBIOLOGICAL LIMITS FOR FROZEN PRECOOKED FOODS

Glenn G. Slocum
Division of Microbiology, U. S. Food and Drug Administration

Ever increasing development, production, and marketing of a wide variety of non-sterile convenience foods has inevitably focused attention upon microbiological standards or limits for such products. The transfer of food preparation from the home kitchen to the factory on such a massive scale has placed a responsibility upon the food industries and regulatory agencies to insure that the foods reaching consumers are prepared under good sanitary conditions and are safe, clean, and sound.

Frozen products, particularly frozen precooked foods, constitute an important class of convenience foods. Some are thawed and eaten without further treatment by the consumer; some are warmed to a palatable temperature and others require a degree of additional cooking in preparation for the table which may or may not result in substantial reduction of contaminating microorganisms. In common with other cooked foods, these products are excellent substrates for the growth of microorganisms. Recontamination of cooked ingredients during processing and subsequent exposure to time-temperature conditions favorable for bacterial development can, therefore, result in spoilage and, conceivably, toxic or infectious products.

The health record of frozen foods is indeed excellent - one of which the industry can be proud. There are few published reports of food poisoning implicating frozen foods and possibly none establishing a cause and effect relationship beyond reasonable doubt. We have investigated several cases in which frozen precooked foods have been suspect on epidemiological grounds but in no case has a portion of the food actually eaten been available and in no case has a known food-poisoning agent been demonstrated in the frozen food available for examination.

These facts, however, give little room for complacency. Let us look at some of the reasons:

1. Investigation and reporting of food poisoning is grossly incomplete, inadequate, and does not supply any firm basis for evaluating the hazard from different classes of foods. Most of those reported are mass outbreaks. Individual or sporadic cases rarely attract attention and receive investigation. This would be the more likely pattern with frozen precooked foods packaged in individual portions. In addition, our total experience with these products is somewhat limited. This is a comparatively new and young industry which has come into being largely in the last decade and has become truly large in about the last five years. As new firms, new products and expanded volumes develop, the risks will tend to increase and we can expect untoward events to occur.

2. We must also be concerned about the potential hazard from such products. This industry is no different basically from other segments of the food industry. It is made up of firms varying widely

in facilities and competency for the production and control of the finished products. A few are excellent, many are average, and some are very poor. Conditions observed during our survey and the levels of contamination found in the products from some of the plants are not reassuring. The potentiality for harm must be considered real. A serious outbreak of illnesses resulting from frozen foods would reflect upon the industry and regulatory officials alike.

3. It is, of course, fundamental that the public is entitled to receive clean, sound frozen products produced under good sanitary conditions. Ultimately, compliance with these requirements provides the best overall assurance of safe products. We are concerned today with one of the means for achieving this goal, namely, through the establishment of microbiological standards for frozen foods.

Within AFDOUS, consideration of such standards has been limited to frozen precooked foods and specifically to frozen pot pies and complete dinners. The bulk of these products contain meat and poultry ingredients and are produced under official inspection of the U. S. Department of Agriculture. Hence, they have not figured importantly in our F.D.A. studies and I defer to other members of the panel in this area.

There is currently wide interest in extending the use of microbiological standards to food products. On June 8-9, 1960, a conference on this subject was held under the sponsorship of the Division of Medical Sciences of the National Academy of Sciences - National Research Council. One section of the report of this conference (Public Health Reports 75:815-822, September 1960) seems to sum up well the present situation.

"The immediate practical achievement of the conference was to agree on the need to seek support through the NAS-NRC, and its working committees, for continuing and expanding efforts to develop and apply standards. The practical value of such standards were believed to be foreshadowed by past achievements. However, none felt that microbiological standards by themselves would suffice to protect consumers from infection, poison, or spoilage. The gains in public health protection, it was agreed, would require further advances in the knowledge and practice of sanitation by professionals and technicians, commercial interests, and consumers. There was no issue between realists and perfectionists: all accepted the virtue of directing attention towards specific situations where microbiological standards seem most likely to improve the safety and quality of mass-market foods."

I think we must recognize that frozen precooked foods are candidates which will be thoroughly appraised in present and future considerations.

In F.D.A. we are conducting studies on the microbiology of frozen precooked foods in relation to factory sanitation. We hope to publish the first report of a rather general survey of plants and products in the near future. The survey covers such a wide variety of products and conditions that specific conclusions regarding limits cannot be made at this time. Certainly, levels of contamination observed were frequently correlated with sanitary conditions and practices in the processing plants and thus indicate the potential value

which might be derived from established standards as a means of obtaining improvement in factory sanitation.

We are dealing, however, with a complex situation in which differences between products, processing practices, and composition profoundly influence the microbial content of the finished products and no single or universal standard would be applicable or adequate for all.

For example, products prepared from components cooked early in production and subsequently handled, generally contain higher organism levels than those cooked late in the processing operation. The final cook applied to many products such as crab cakes, fish cakes, fish sticks, croquettes and a variety of specialty items usually so reduces the bacterial content that the objective findings on the finished product fail to reveal the previous sanitary history. But here again differences in the time and temperature of the cook are important as indicated by the following results:

Fish Sticks

	Plant A		Plant B
	Insanitary		Above average
Raw fish	560,000		65,000
Batter (used 10 hrs.)	12,000,000	(used 30 min.)	210,000
Fish & batter	2,000,000		260,000
Fried 90 seconds	700	30 seconds	95,000

The presence or absence of certain ingredients and whether they are added before or after cooking also markedly influence the results. The addition of such materials as raw egg or raw cheese to cooked products will of course contribute substantially to the number and types of organisms present. The interpretation of bacteriological findings under these circumstances is, in many cases, difficult without access to pertinent factory information.

I was quite impressed by a statement made by Dr. G. S. Wilson, eminent English microbiologist and Director, Public Health Laboratory Service, London, in 1955 (J. Applied Bacteriology 18:629-630, 1955) in summing up a symposium on food microbiology and public health:

"On one point I am clear, namely that it is far more important to lay down a strict code for the preparation or processing of food and see that it is carried out properly than to rely on bacteriological sampling of the finished product. Bacteriologists have a considerable part to play, but if they are wise they will spend their energies in devising means of preventing or overcoming contamination rather than in pandering to the demand of sanitary authorities for more and more sampling. Samples are essential, and a simple reliable technique for examining samples is essential, but sampling can be no more than a check on the efficacy of the processing; and it is the high

quality of the processing maintained day after day that is required to ensure the safety of many of our foods."

Thus Dr. Wilson indicates his clear preference for control at the source of production through plant inspection and processing requirements as against a system based primarily upon the sampling and analysis of finished products, presumably to be measured against established limits. I find myself in agreement with Dr. Wilson. If I have any quarrel with him, it is that in mentioning the importance of sampling and analysis as a check on the efficacy of processing, he fails to point out that this is the only means available where the processing plant is beyond the jurisdiction of the immediate control authority. I know the English are giving great attention to imported foods and we are becoming much more aware of this fact as the importation of frozen precooked foods into this country increases. Thus, we understand and sympathize with State and local officials who must rely upon objective analysis as a basis for the control of such products, and will continue our studies in cooperation with AFDOUS and as a basis for our enforcement program.

In the meantime, F.D.A. is developing a regulatory program on frozen precooked foods for initiation in the near future. Although still in the formative stage, the program will be based essentially upon the factory inspection approach with the evaluation of sanitary conditions and practices by bacteriological methods, including the examination of factory samples and finished products.

MICROBIOLOGICAL STANDARDS FOR FROZEN FOODS

M. F. Gunderson
Associate Director of Bacteriological Research
Campbell Soup Company, Camden, N. J.

Proper frame of reference in considering frozen foods. Precooked frozen foods represent a particular category of foods which are to be heated before they are eaten. These foods, therefore, should attain pasteurization temperature before the consumer partakes of them. There are some 501 or more such items in the frozen food cabinet in the supermarkets spread over the land. These foods are maintained in the frozen state wherein microbial action is arrested.

In considering foods such as this, we should use the proper frame of reference and not hark back to what we know about milk, food, and water bacteriology learned through the experiences of higher temperatures. We should consider our subject in reference to the temperature at which we find it throughout its market life. Frozen Foods require investigations into low-temperature bacteriology, and a whole new field of research is thereby awaiting us.

The modern supermarket has a host of other consumer items apart from frozen foods in which quality changes, due to microbial action, take place with greater rapidity. I refer you to the packaged meat cases, the dairy cases, the fish counter, and other areas wherein the temperature is not approaching zero, but approaches 32°F.

Market survey and National Association of Frozen Food Packers. In our consideration of the contents of a frozen food case, we have enlisted the assistance of the National Association of Frozen Food Packers and have surveyed the market to determine what we are doing now, as of the fall of 1960. We obtained data on several examples of ready-to-heat-and-serve frozen foods, ranging from chicken pot pies to beef pot pies, frozen platters, such as turkey, and also turkey pies. 1/ This is what the producer is doing without compulsion or duress. Those with counts felt to be out of line are notified by the National Association of Frozen Food Packers, and they have been sent copies of this survey. Excellent response has been had, and proper steps have been taken to improve their position with respect to the other brands tested. Future market surveys will test this market and determine how effective we have been.

The research committee of NAFFP has agreed that each area laboratory in the eastern part of the United States, the western part of the United States, the north, the south, and so on, will test 250 samples in the retail market of their area, and these samples will be funneled into NAFFP for informative action with the producers. This represents a positive approach and one which has certainly been effective.

1/ Available from National Association of Frozen Food Packers.

We do not believe in firm standards, since good food might be wasted. However, we would accept the position which NAFFP has suggested, and that is a total count of 100,000 organisms per gram, with no mention made of coliforms or staphylococci. Laws on the books already permit Food and Drug officials to deal with foods containing a significant population of these organisms. The information given here, together with the projected improvement which we will expect, should indicate to you that these frozen foods show a microbial record far better than most of the consumer items offered for sale in the perishable section of the supermarket.

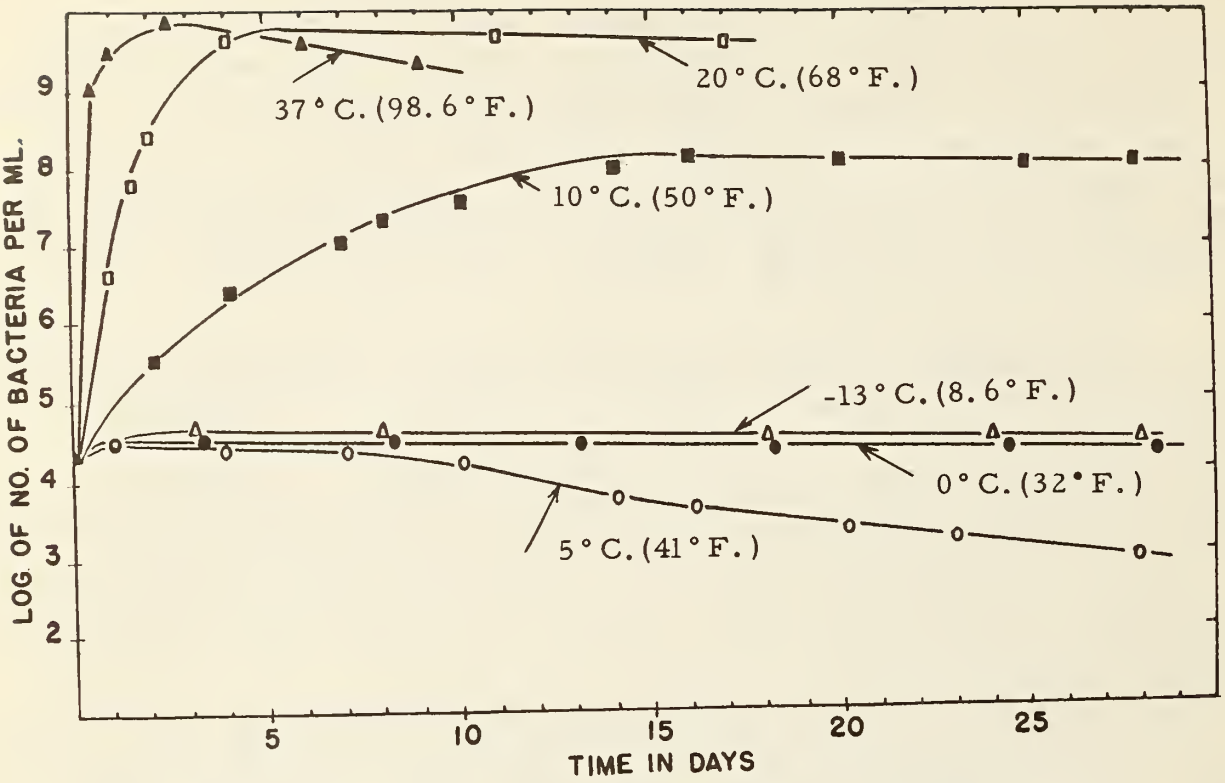
Melting points for frozen products. There is another point to consider and that is: When is a frozen product truly frozen? This has importance because we will find enzymatic degradation whenever there is free water available, and we will also find microbial growth, slow to be sure, but certain, when free water or available water is present. To this end, we have undertaken to determine the melting point of several frozen products. We find that melting points vary from 15.2°F. to 29.5°F. Mince pies, for example, have a melting point of 15.2°F. A chicken pie has a melting point of 29.5°F. Melting points, therefore, extend through at least half of the temperatures available above 0°F., that is, 15°F. to 30°F. This is an important consideration since product must be maintained below its melting point in order to maintain the integrity of the product, and if it is to be truly hard frozen, it must be several degrees below the melting point. Therefore, we are in agreement with 0°F. for display cases, although excursions above this temperature for a short time are not going to do a great deal of damage.

Growth curves. You have seen the results from our market survey. You have seen the population of staphylococci and coliforms listed. These populations have not been large populations, and it is almost impossible for them to get any greater in number. By accident, biological, to be sure, the frozen food industry happened to go from elevated temperatures to as low a temperature as possible, and in so doing precluded the possibility of encouraging a public health hazard. The frozen food industry learned to cool components rapidly, and our survey shows that this they did learn. The frozen food industry learned to freeze product rapidly and to keep it frozen. These lessons were learned through lessons in disaster.

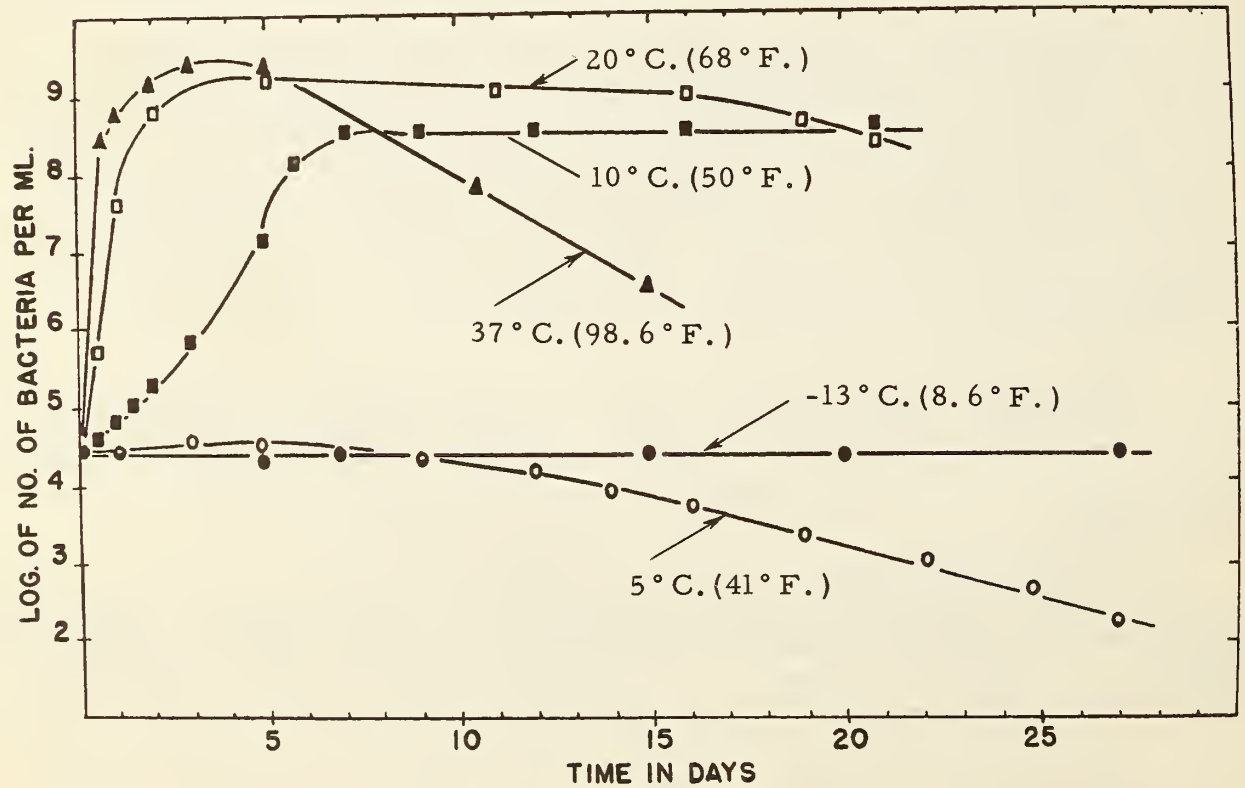
These disasters were sour and spoiled product, which of necessity had to be thrown away. These expensive lessons taught the frozen food industry the lesson of proper materials handling. However, let us see what the Biology of Bacteria will teach us and how this came to be the salvation of the frozen food industry.

I call your attention to the growth curve for Staphylococcus aureus in chicken gravy. You will note the curve for 5°C., or 41°F. You will note that the staphylococci tend to disappear with time at this particular temperature. However, in foods hard frozen at -13°C., or 9° F., neither multiplication nor death ensues. This same thing is true at 32°F.

The situation is static. At 50°F. (10°C.), which is the middle curve and which is also the temperature of the old ice refrigerator, growth proceeds



GROWTH CURVES OF Staph. aureus IN CHICKEN GRAVY



GROWTH CURVES OF E. coli IN CHICKEN GRAVY

slowly, and with time a population does develop. However, the old ice refrigerator could hold foods for a day or two with some assurance. You will note the same truths with Escherichia coli, which I have taken as a representative of the gram negative organisms - the Salmonella. Therefore, even at defrost temperatures, frozen foods do not offer a suitable medium for the development of organisms of public health significance.

There have been forty billion pounds of frozen foods sold and presumably eaten since the beginning of the frozen food era, and there is not one well authenticated case of food poisoning due to commercially prepared frozen convenience foods such as those represented in the market survey. On the other hand, spoilage will take place at defrost temperatures, and I refer you to the behavior of psychrophiles at temperatures of 41°F. or 32°F. Frozen foods will rot at defrost temperatures. Indeed, the enzymes of psychrophiles will digest the components of frozen foods at these temperatures whether the organisms are present or not. So, bear in mind the relationship of storage temperatures to the outcome insofar as frozen foods of this sort are concerned.

Staphylococci in competition. Now, there is another matter to consider. We have never given a thought, previously, as to what will happen to an emerging population of staphylococci when faced with an emerging population of psychrophiles at the lower scale of the thermometer. We are, and have been, working on this problem and we find that staphylococci do not do well in competition with psychrophiles at temperatures up to 68°F. For that matter, in a well mixed population, they do not do too well at higher temperatures. Staphylococcal food poisoning occurs in a product which was essentially sterile once, or is inhibitory, as in a salted ham. Cream sauce, ham, and other susceptible foods coming down through the twilight zone from 100°F., 90°F., 80°F., and so forth, and passing through these areas of temperature slowly will, if inoculated with staphylococci, permit the rapid development of a population sufficient to cause trouble.

On the other hand, product coming from zero temperatures upward do not pass through this twilight zone, and the staphylococci are not permitted to multiply in the face of the competition of other organisms.

Of course, if product containing staph toxin is frozen, this will be another story, but this eventually has nothing to do with the imposition of microbial standards, since such a product could have been pasteurized and still be a hazard.

Contamination in normal proportions. Since what has been said is quite evident and since at this time it will not be possible to produce frozen foods which are bacteriologically sterile, let us produce frozen foods with as low a microbial content as is possible. On the other hand, let us hope that the bacteriological flora of frozen foods contains organisms in their natural proportions so that we have competition in the population which emerges during a period of defrost and so that frozen foods will have their own built-in defrost indicator; namely, the psychrophiles which will cause a product to become organoleptically unsatisfactory and will be unacceptable to the consumer.

Proper appraisal of laboratory results. There is another matter and that is the laboratory in relation to frozen food microbiology. Most of the methods that are used in a food laboratory have been borrowed, or adapted, from laboratories dealing with diagnostic problems or public health problems. Also, many of the people employing these tests and procedures are indoctrinated with medical microbiology and, for example, might not know that Alpha-hemolytic streptococci are not necessarily of any effect when found in the cheese portion of a frozen dinner, since, when we find them under these circumstances, these organisms represent legitimate useful cheese starter organisms. Also, the individual doing frozen food microbiology must be wary of the effects of food ingredients of differential media. The sucrose from the frozen peaches, or the coconut, will contaminate his differential media for coliforms and thus yield falsely positive results. These dangers are inherent in every differential medium employed since the food ingredients added to these types of media will influence the characteristics of the results.

In conclusion, we feel that we do not know enough about the characteristics of the entire gamut of frozen foods. A great deal of work remains to be done, such as the market survey. We need more such surveys. We need to explore the entire matter of modern perishable food handling and not belabor frozen foods as a class set apart, and we certainly must not reason from analogy that what happens to foods at higher temperatures is what will happen to frozen foods at temperatures of freezing and even at temperatures of defrost. We should emphasize that freezing retains quality and the original integrity of the frozen product and puts a stop to microbial development.

CONSIDERATION CONCERNING MICROBIOLOGICAL STANDARDS FOR FROZEN FOODS

P. J. Brandly
Biological Control Laboratory, Meat Inspection Division
Agricultural Research Service, USDA

The spectacular and far-reaching contributions to human welfare made by the microbiologists have never been fully appreciated nor completely elucidated. The establishment of scientific facts which refuted such supernatural theories as spontaneous generation of life and miasmic disease ruptured the confining membranes of established dogma. Almost a century has passed since Pasteur's and Koch's achievements sired a sound basis for microbiology. The inquiring minds of that time which were not confined by preconceived theories knew no frontiers and the blossoming age of bacteriology bore golden fruits for all mankind.

Have we, with our established bacteriological theories, become myopic and bound by dogma which blinds us to a discerning evaluation of the real significance of bacterial numbers and coliform counts? Have we, in our search for a simple answer to a very difficult problem, fallen prey to self-deception? Are we realistic in attempting to apply methods and techniques, which have proved successful for water and dairy products, to foods which are to be cooked before consumption?

A food control program based upon numbers of viable bacteria in foods which are to be cooked before consumption is completely unrealistic if it fails to take into account the following facts: (1) Hamburgers, which are regularly eaten partially cooked, commonly contain organisms in excess of ten million per gram with coliform counts averaging 8,000 per gram. (2) The establishment of standards for low bacterial counts inevitably results in the demand for the use of preservatives or the over-cooking and repasteurization which lessens quality of the product. (3) The establishment of bacterial standards misleads the consumer in that he believes low bacterial counts are an evidence of quality.

Relative to bacterial counts in hamburger, our recent experience with a series of samples shows that beef which has been aged for three weeks prior to distribution to the retail trade will usually produce counts in excess of 25 million per gram when the local butcher grinds the trimmings and other cuts into the hamburger. The counts are made on veal infusion agar incubated at 25° C. If nutrient agar incubated at 37° C. is employed, the counts will usually be much less than and almost never more than one-tenth those on veal infusion agar at 25° C.

We feel that bacterial numbers of non-pathogenic organisms are not significant until their presence is grossly detectable. The concurrent drive of some members of the chemical and food industry to add bacteriostatic agents and fungicides is so great and so much emphasis is placed upon low levels of bacteria by these people that they have given the impression that the use of chemical preservatives is a necessity for food distribution. Is it not possible that these food spoilage organisms are of tremendous benefit

to the consumer in that they maintain a vigilance over the product by spoiling it or reducing its quality if it is not handled properly?

Low bacterial counts obtained by careful sanitary practice of clean and wholesome articles handled at temperatures which negate or stop bacterial growth and which are distributed rapidly so that they arrive in the consumer's kitchen in a fresh unaltered condition are indeed commendable. However, a food which has low bacterial counts as a result of pasteurization or the addition of bacteriostatic preservatives certainly is misleading to the consumer if the food is evaluated by its bacterial load.

The granting of permission for use of preservatives which allows for sloppy sanitary practice, poor slow inefficient sales and distribution procedures, and sloppy handling at the retail level certainly is a disservice to the consumer. Preservatives may prevent the spoilage of food and effect a minor economy here and there, but the price which the consumer pays for staleness, for the tolerance of unsanitary practices, for blatant disregard for common decency consideration, is too great a price to pay for the minimal advantage that the processor gains by the use of preservatives.

In considering the third point, not only is the consumer misled but the producer, if he pasteurizes his product at final packaging, somehow feels that he has completely fulfilled his obligation to the consumer. His incentive for improved quality is destroyed and common decency considerations, as well as quality considerations, no longer have an important place in his calculations.

The successful use of E. coli as an evidence of fecal contamination in water has been such as to sanctify it in the minds of some microbiologists. Until comparatively recent times every State health department would run a bacteriological sample of any water submitted and certify as to its safety. The continued appearance of typhoid resulting from this certified water caused re-evaluation which showed the need for "at-the-source" inspection. The at-the-source inspection of food is as necessary if wholesomeness and acceptability is to be assured.

Aside from these important scientific and practical considerations, the legal aspects of bacteriological standards for food must be recognized. For a discussion of the forensic aspects of this problem, reference is made to the short summary by M. Ingram which appeared in the program of the 20th Annual Meeting of the Institute of Food Technologists held in San Francisco, May 15 - 19, 1960.

The important contribution which the science of bacteriology can make to a food control program is well recognized. As evidence, I point to an additional bacteriological laboratory which has been recently established in Philadelphia by the Meat Inspection Division to further service the "at-the-source" inspection personnel. Bacteriology has important capabilities not available anywhere else; however, if we are to reap the full benefits which this discipline can provide, we must direct its use to the areas where it can make realistic contributions. To misuse bacteriology in an attempt to devise a simple answer to the complicated problem of establishing wholesomeness of food is unfair to the consumer and the science.

SUMMARIZING STATEMENTS

Harold Clark, Chief, Food Division
Department of Consumer Protection, State of Connecticut
Hartford, Connecticut

(Mr. Milton Duffy expressed his sincere appreciation to Dr. Copley, Director, to William F. Talburt, Assistant Director, and to the staff of the Laboratory here on behalf of the members of the Frozen, Canned and Processed Food Committee and also the officials of AFDOUS. Mr. Duffy said that it had been a very worthwhile meeting and he was happy to have been privileged to attend and that he would turn over the summary of the meeting to Harold Clark, Vice Chairman of the Frozen, Canned and Processed Food Committee and also an executive board member of AFDOUS.)

Mr. Chairman, Dr. Copley, Fred Talburt, members of the staff of the Western Utilization Research and Development Division and friends: I am indeed happy to be privileged to attend this very worthwhile seminar that has been conducted here for the past two days. I did not realize until a short time ago that I was going to be called upon to summarize this conference.

This, however, has been one of the best conferences which I have ever been privileged to attend. The technical knowledge which has been presented by Dr. Copley and his associates covering research on time and temperature studies of frozen foods since 1948 has not only been extremely valuable to those who have attended this meeting, but also to the members of the Frozen Food Committee and to AFDOUS officials.

We as regulatory officials have been dealing with this subject of time and temperature for frozen foods for several years. In 1953 the Connecticut General Assembly passed one of the first laws authorizing the Commissioner to draft regulations dealing with the manufacture, transportation, storage and retail sales of frozen foods in Connecticut. Shortly after the passage of that act, one of the first persons to come to my office to discuss frozen food regulations was my good friend, Dutch Diehl. At that time we discussed regulations from various aspects, covering phases of the industry, and we both agreed that it might be better to defer action on the drafting of regulations until a broader look at the entire industry had been taken.

As you know, Connecticut has been most patient with this situation. Some seven years have already elapsed and we are still looking at the entire picture. We in Connecticut were not trying to make headlines as the first state in the Union to adopt the frozen food regulations. Instead we have waited to get all the facts.

This two-day seminar has been one in which many important phases of the frozen food industry have been thoroughly explained from a highly technical viewpoint. The research information presented clearly indicates that zero degree temperatures or lower are what is needed for frozen foods, and

secondly that temperatures above zero degrees, even though held for a short time, do have a deleterious effect on the quality of frozen foods. It has been made crystal clear here that exposures to unfavorable temperatures above zero for short periods do create quality-factor losses which may not be readily detected by the consuming public, but which can be detected by a panel of experts. It has also been made clear that these foods should not deteriorate in quality to the extent that the consumer would ever make such a detection. Thus it can be seen that in order to accomplish these objectives, it is a must that frozen foods be kept at zero degrees or lower.

The Frozen Food All-Industry Coordinating Committee is apparently attempting to get to the grass roots of the Frozen Food Industry to improve many of the practices now existing which are not conducive to high quality. We as regulatory officials and members of AFDOUS appreciate the endeavors of the Frozen Food All-Industry Committee and sincerely hope that they will go forward and attempt to improve many of the unfavorable conditions that exist today. We do not, however, as regulatory officials, approve or condone the taking of action by this Frozen Food All-Industry Coordinating Committee as a substitute for regulatory measures at the state levels. We believe that it would be fine if industry and regulatory officials could get together and come to a mutual agreement with regard to regulations which would be enforced throughout the entire country. It would be far better for industry to be able to operate under one uniform set of regulations than to be subjected to different regulations in many different states. We sincerely hope that the Frozen Food All-Industry Coordinating Committee will continue their crusade, so that we will begin to see the fruits of their labors.

We again thank Dr. Copley, Fred Talburt, and the entire staff for the very fine meeting we have had here and for the many courtesies extended to all of us while we had the privilege to be in California.

SUMMARIZING STATEMENT

H. C. Diehl, Chairman
Frozen Foods All-Industry Coordinating Committee

This meeting is unique in the history of the American food industry. There have been very few, if any, occasions when representatives of all segments of one of the food preservation industries have met with those responsible for protecting public health and interest, in relation to foods, in order to consider the technical facts by which the successful art and practice are determined.

Dr. Copley and his staff members have given us information of much significance and value and I am certain that it has substantially enlarged our understanding of frozen food character, behavior, and bacteriology.

It has been said that if only the frozen foods industry would go into action on matters of quality control "instead of sitting on its hands," as an official once put it, then the achievement of the zero degree temperature goal would be easy.

Scientific facts are not manufactured with the dispatch of a sausage-making machine nor is the industrial implementation of such facts an instantaneous matter.

The time-temperature tolerance investigations, which our committee recognizes as the sole basis for our voluntary industrial program of quality and environmental control, were begun in 1948, 12 years ago; the investigations jointly sponsored by ATA, TTMA, USDA, and National Bureau of Standards began over 5 years ago -- to mention but two examples of industrial action, initiated by industry sponsorship before the AFDOUS Code was considered.

Let us be realistic. There are two matters involved here. One is the problem of spoilage, which can potentially affect public health or which renders the food unwholesome.

The other is the voluntary industry effort to maintain a high quality level in frozen foods in order to expand the American market for these appetizing and useful products.

By consensus generally (scientific and industrial) this goal is achievable in time by the adoption of improved handling practices in a consistent control and educational program. This is the major objective of our committee action. It is wholly unrealistic and arbitrary to expect that this goal can be reached at once. I am certain that I do not have to enlarge upon that point to this audience.

Time is an essential component of many facts of frozen food preservation; it is also a necessary component of our industrial program.

And may I ask, What justifies the haste and urgency of some, who have insisted that industry must conform at once to the zero degree temperature goal in all facets of its action -- or else?

We have heard that there is no significant growth of food microorganisms at plus 15°F. or below. We have been reminded again that time as well as temperature is a factor in quality loss. We have been shown that, while there is an increasing quality loss in time, as environmental temperature rises, the rate of loss is relatively small in the range of temperature just above zero especially if the time is comparatively short. We know that public health is not menaced by frozen foods if their temperature rises for a limited time in the zero to plus 15°F. range during the unavoidable (at least, presently) sequences of transport, distribution, and merchandising. Industry is actively striving to limit these increases in environmental and product temperature and marked improvement is already in effect.

All foods, fresh or preserved, must be moved in this large country of ours from producing areas to consumer. All foods undergo some change in the time required for this movement in the pipelines of distribution. This fact is known and traditionally accepted.

As Lee Smith has said, the consumer is the judge as to whether the original product quality and the degree of product protection, reflected in the product as consumed, meets with sufficient approval to give the product a consistent place in the market. Product quality and its protection, insofar as public health is not menaced or public deception is not involved, remains a traditional responsibility of industry in the free competition of the American economy.

If your product does not please the public, you will have to change the quality or the protection given to it, or you are out of the market.

Frozen foods have a very satisfactory record through the years, comparatively, in regard to public health problems. The market for frozen foods has grown extensively in a generation; hence in the main, they must have qualities acceptable to the consumer.

It has been said here that we really have two matters before us: (1) the voluntary quality control program of industry and (2) the usual problems of protecting public health and public interest, in regard to which, in principle, frozen foods are not basically different from other preserved food products. It is good to have these facts clarified at long last.

It has also been constructively suggested by Mr. Abrahamson that a small group from the committee meet with a small group from AFDOUS to bring the objectives of each group into mutually acceptable focus. We favor this suggestion because in an atmosphere of mutual understanding, rather than one of mutual irritation, based on arbitrary or unilateral misconceptions, we doubtless can arrive at an acceptable modus vivendi, since actually both groups are interested in knowing and in acting on actual facts rather than on individual subjective interpretations.

We welcome the cooperation of our friends in AFDOUS, because we are genuinely devoted to making the quality of frozen foods even better, so that the frozen foods industry may better serve the health and welfare of the American people and thus logically deserve a larger share in the food market.

All of us thank our hosts, the Western Regional Research Laboratory of USDA, for an exceptionally profitable two-day seminar, which has doubtless required many hours of careful planning in order to make the program as useful to us as it has been. We also commend the sustained loyalty and interest of the personnel engaged in the Time-Temperature Tolerance Investigations through the years, which have given such valuable and comprehensive information to guide an industry in its technology and business.

GPO 981277

Growth Through Agricultural Progress